Economic Geology of the Panamint Butte Quadrangle and Modoc District, Inyo County, California

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ABSTRACT

The Panamint Butte quadrangle is in central Inyo County, California, partly within Death Valley National Monument. The area includes the northern parts of the Argus Range, Panamint Valley, and Panamint Range. The northern half of the Modoc district is in the southwestern part of the quadrangle. In order to study the Modoc district as a unit, 10 square miles that includes the south half of the district was mapped in the northwest part of the Maturango Peak quadrangle.

The Panamint Butte quadrangle is underlain by a sequence, about 15,000 feet thick, of metamorphic and sedimentary rocks of Precambrian(?) to Permian age that is intruded by quartz monzonite plutons of Jurassic(?) age and andesite porphyry dikes of Cretaceous(?) age. Late Cenozoic volcanic rocks and sedimentary deposits unconformably overlie the older rocks.

Late Precambrian(?) metamorphic rocks, which include micaceous and limy quartzite, mica schist, biotite-hornblende gneiss, and dolomite, are limited to three small exposures in the Panamint Range and Panamint Valley. Paleozoic strata range in age from Middle(?) Cambrian to Permian in a conformable sequence approximately 14,000 feet thick. Silurian and older Paleozoic rocks are exposed only in the Panamint Range; they consist mainly of dolomite but include lesser quartzite, limestone, and shale. Devonian and younger Paleozoic rocks are exposed both in the Panamint and Argus Ranges. They consist predominantly of limestone, marble, and silty limestone.

Quartz monzonite plutons of Jurassic(?) age intrude the Precambrian(?) and Paleozoic strata in both the Panamint and Argus Ranges. All mineral deposits with a known production are within 1½ miles of one of these intrusions. A swarm of altered andesite porphyry dikes of Cretaceous(?) age striking N. 70° W. intrude the Paleozoic rocks and locally the quartz monzonite in the Argus Range south and southwest of Panamint Springs. Late Cenozoic deposits cover most of Panamint Valley and the Panamint Range south of State Highway 190.

Three periods of deformation are recognized. The earliest orogeny, late Mesozoic, formed broad open folds that trend north to N. 20° W. in the Argus and Panamint Ranges. Thrust faulting accompanied folding in the Panamint Range. The second period of deformation was caused by forcible intrusion of quartz monzonite plutons of Jurassic(?) age, which deformed both the broad folds and the thrust faults. This was followed by a long period of erosion until the late Cenozoic when extensive regional warps and accompanying strike-slip and normal faults formed the present basin and range topography.

Total value of the production of lead, silver, zinc, copper, and gold is about $3,900,000. Lead and silver from the Modoc district account for all but $160,000 of this amount. The first production of lead-silver ore came from the Modoc district in 1875, and $1,900,000 in silver, gold, and lead was produced by 1890. This was mostly from the Modoc mine. The Minnietta mine produced approximately $600,000 in silver, gold, and lead since 1895; no significant production was recorded after 1954. Most of the production from the Defense and Surprise mines came after 1947.

Ore in the Modoc district is in marble of Devonian and Mississippian age whereas silty limestone of Pennsylvanian and Permian age is unfavorable. The ore bodies are small but high grade. Galena is the principal primary ore mineral; secondary ore in the Modoc district is manganese-rich and contains cerussite, relict galena, coronadite, jasper, cryptomelane, and pyrolusite.

The lead-silver mines in the Panamint Range are small and account for only $70,000 of the total production of the Panamint Butte quadrangle. The Lemoigne mine on the east side of the Panamint Range produced some galena and siliceous silver ore between 1925 and 1927. The Big Four mine on the west side of the Panamint Range produced oxidized lead ore associated with hematite and jasper between 1944 and 1952. The host rock at the Lemoigne mine is dolomite of Cambrian(?) age, whereas at the Big Four mine the host rocks are marble and limestone of Pennsylvanian age that are thrust over marble and dolomite of Ordovician age.

Gold production from the Panamint Butte quadrangle is small, slightly exceeding 2,500 ounces; most of the gold came from lead-silver ore. Uranium has been found in small pockets in Osborne Canyon in the Argus Range, but no production has been recorded. Nonmetallic commodities in the Panamint Butte quadrangle have not been exploited. They include limestone, dolomite, and limy clay.

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INTRODUCTION

PURPOSE AND SCOPE

This study of the Panamint Butte quadrangle is part of a long range program by the U. S. Geological Survey in cooperation with the California Division of Mines to study the Inyo County lead-silver-zinc deposits. The deposits lie within a mineralized belt 120 miles long that extends from the Inyo Mountains southeast to the Resting Spring district in the Tecopa quadrangle. The Panamint Butte quadrangle includes the northern half of the Modoc district and several small mines in the Panamint Range (fig. 1). In order to study the Modoc district as a unit, 10 square miles in the northwest part of the Maturango Peak quadrangle, which contains the remainder of the district, was included in the area to be mapped.

The project entailed mapping the Panamint Butte quadrangle on a scale of 1:40,000; mapping the Modoc district on a scale of 1:20,000; and detailed studies of individual deposits. This report presents the economic results of the study. Included are detailed descriptions and large-scale maps of all the lead-silver mines that have a recorded production and a geologic map of the Modoc district. An economic map of the Panamint Butte quadrangle shows the location of all mines and prospects, their relative importance, and their relation to lithology and to major faults (pl. 1). A detailed geologic quadrangle map and a description of the general geology will be published in a later report.

GEOGRAPHY

Location and accessibility

The Panamint Butte quadrangle is in central Inyo County in southeastern California partly within Death Valley National Monument between longitude 117°15′ and 117°30′W. and latitude 36°15′ and 36°30′N. (fig. 1). The area includes the northern Argus Range, Panamint Valley, and part of the Panamint Range. The only settlements within the area are a resort motel, restaurant, and State Highway Department office at Panamint Springs and small mining camps at the Minnietta and Defense mines. Very little evidence exists of the old town of Lookout, which was an active mining town on Lookout Mountain during the 1880's.

Access to the quadrangle is provided by two improved roads. State Highway 190, which runs from U. S. Highway 6 in Owens Valley to Death Valley, crosses the central part of the quadrangle and an improved county road provides access from Trona (fig. 1). Trona and Lone Pine, 38 miles south and 46 miles west of the quadrangle respectively, are the closest supply centers. Ore from the area is trucked south to the railroad at Trona or west to Keeler or Lone Pine. Gravel roads lead to all the producing mines. Some of the roads are steep and are best negotiated with a 4-wheel drive vehicle. Roads to mines that have been closed several years are usually in poor condition.

A 4-wheel drive vehicle provides access to some parts of the quadrangle that are miles from any road. Although tedious, it is possible to drive to the foot of Mill Canyon at the head of Panamint Valley in the northwest part of the quadrangle, and without much difficulty to the head of Panamint Valley to sec. 6, T. 17 S., R. 42 E. skirting the east side of the sand dunes (pl. 1). Two canyons in the Panamint Range are accessible. One is Dolomite Canyon 2 miles north of State Highway 190, which is accessible to an altitude of about 3,800 feet by 4-wheel drive vehicle. The other is Lemoigne Canyon 1¼ miles north of the Lemoigne mine. A small jeep can be driven with difficulty to an altitude of 4,200 feet, and a trail goes to the top of the range and continues northward to Cottonwood Springs in the Marble Canyon quadrangle. The jeep trails are shown on the economic map (pl. 1).

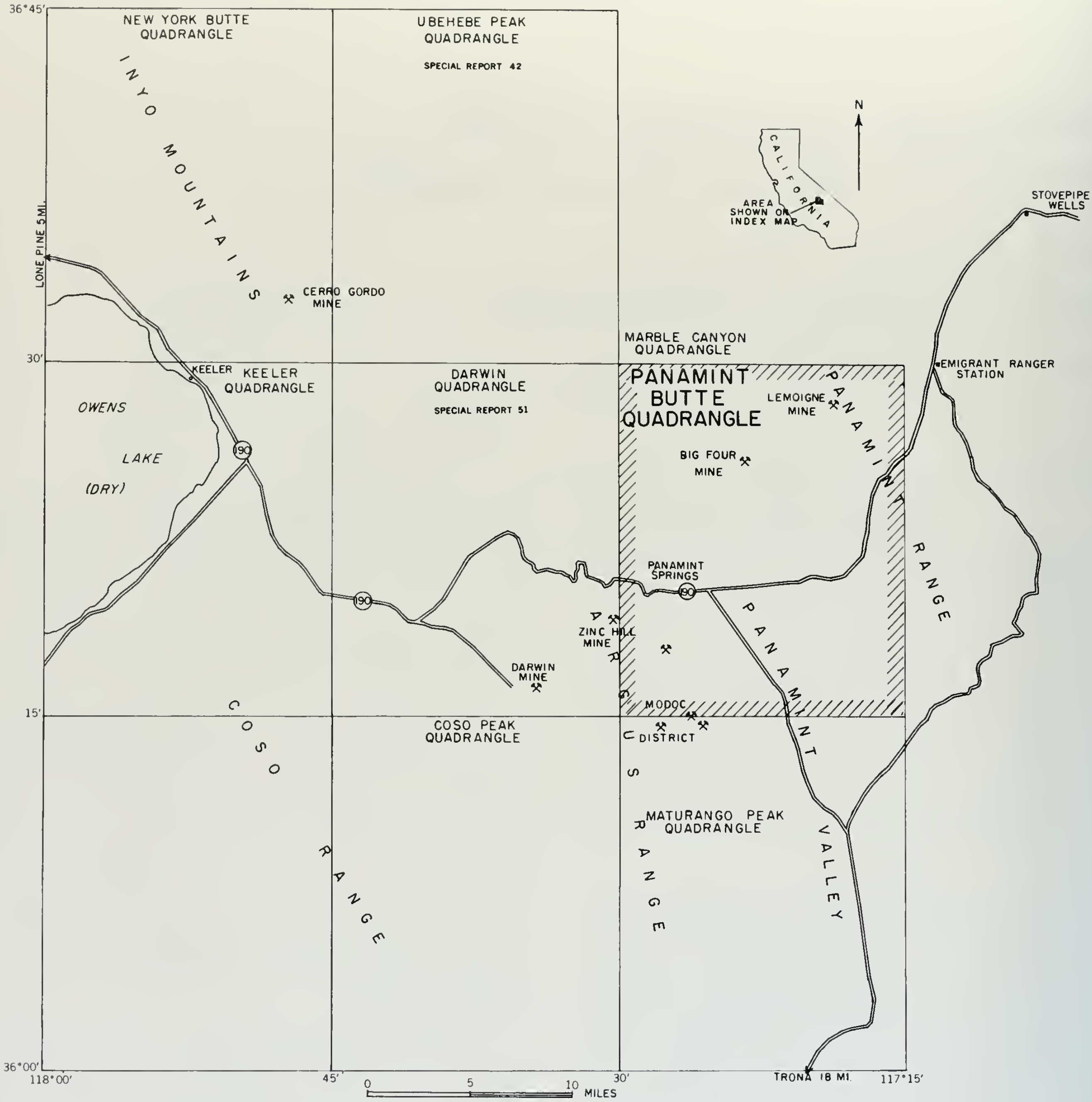

Figure 1. Index map showing the location of the Panamint Butte quadrangle.

Topography

The quadrangle is in the western part of the Basin and Range province. Panamint Valley, a large enclosed basin trending N. 25° W. diagonally across the quadrangle, occupies about a third of it. The floor of the valley is at an altitude of 1,542 feet. The valley is bounded on the east by the Panamint Range and on the west by the Argus Range (fig. 1). The flanks of both ranges are steep, and the difficulty of access is a deterrent to mining or even prospecting. The maximum relief is 5,745 feet in the Panamint Range from peak VABM 7287 westward 4½ miles to the playa in Panamint Valley, and local relief on this peak is 4,800 feet in 2¼ miles. The crests of both ranges are broad mature surfaces. In the Panamint Range northeast of Panamint Butte is an extensive area of subdued topography about 5,000 feet in altitude (pl. 1). The altitude increases toward the southeast to a maximum of 7,287 feet. The crest of the Argus Range is a rolling surface 4,000 to 5,800 feet in altitude.

Drainage is into two enclosed basins. The northeast 17 percent drains eastward into Death Valley. The remaining part of the quadrangle drains into Panamint Valley. Panamint Valley itself consists of two basins separated by a divide with an altitude of 1,720 feet. The playa in the northern basin is at an altitude of 1,542 feet; the playa in the southern basin is at 1,021 to 1,043 feet. Only the southeastern corner of the quadrangle drains into the southern basin.

Climate, vegetation, and water supply

The climate is typically arid—characterized by slight rainfall, large range in temperature, and by frequent strong winds. No weather station is within the area; the nearest station is at Trona, 38 miles south of the quadrangle. The altitude at Trona is 1,656 feet, about the same as the northern Panamint Valley basin, and the climate is probably slightly cooler. The following data for Trona are from *Climatological data for the year 1946, (Anonymous, 1946)*:

Trona (elevation 1,656 feet)

Annual mean temperature	66.6°F
Highest temperature	115°F
Lowest temperature	20°F
Annual rainfall	4.86 inches
Snowfall	0

The summer temperatures in or near the floor of Panamint Valley are uncomfortably hot, but are generally very pleasant during the other seasons. Above 5,000 or 6,000 feet the summer temperatures are quite pleasant except for short hot spells, but the winter days are commonly cold and snow may be encountered. Rainfall at all altitudes is scant. The average number of days with precipitation at Trona is 20.

Vegetation is sparse on both the Panamint and Argus Ranges. Steep slopes are essentially bare, but scattered sagebrush grows in the valleys and on moderate slopes and creosote bush grows in some gullies. A few scattered junipers and pinyon pines grow above 5,000 feet in the Panamint Range, and a large stand of Joshua trees grows in the basin at an altitude of 5,200 to 5,400 feet on the northeast side of Panamint Butte.

The water supply is limited to several springs in the Argus Range. No water is available in the Panamint Range within the Panamint Butte quadrangle, and water must be hauled to the mines by truck. A heavy growth of creosote bush in a few gullies indicates occasional seeps, but no flow of water was seen at any place. Two canyons at the north end of Panamint Valley have springs, but both are outside the quadrangle. Mill Canyon has two springs with a strong flow of water in the Ubehebe Peak quadrangle, and the canyon 2.08 miles east of the northwest corner of the quadrangle has water within the Marble Canyon quadrangle. Cottonwood trees grow in both canyons near the springs. These springs are the watering holes for the burros that are generally present at the north end of Panamint Valley. Cottonwood Spring in the Panamint Range about 1 mile north of the quadrangle has a strong flow of water that is fenced off from the burros, and is a reliable source of good water.

Water is obtained for the motel at Panamint Springs from an ample supply at Darwin Falls 3 miles to the west in the Darwin quadrangle. Two springs supply the water for the Defense and Minnietta mines. Other mines bring their water in by truck. The Defense mine obtains its water supply from Jack Gunn Spring, which normally flows approximately 900 gallons per day, and sometimes from French Madam Spring (see pl. 2). The Minnietta mine has a pipeline to Thompson Spring in Thompson Canyon, but the supply is not large. Snow Canyon 2 miles south of Thompson Canyon also has water. The only other spring in the mapped area is near Panamint Springs and supplies the Highway Department; the flow from this spring is small.

PREVIOUS WORK AND ACKNOWLEDGMENTS

Very little information was available previously on the geology of the Panamint Butte area, except for several papers dealing with specific mines or small areas within it. Fragmentary sketches of the early mining activity in the Modoc district can be obtained from Raymond (1877, p. 32), Burchard (1882, p. 39; 1884, p. 164; 1885, p. 104), DeGroot (1890, p. 210), and Crawford (1894, p. 24; 1896, p. 32). Later mining activity is described in California Division of Mines reports on Inyo County by Waring and Huguenin (1919), Tucker and Sampson (1938), and Norman and Stewart (1951).

The earliest geologic map that covers the Panamint Butte quadrangle is a reconnaissance map of southern Nevada and southeastern California by Spurr (1903, pl. 1), who makes a threefold subdivision into fine-grained igneous rocks, coarse porphyritic igneous rocks, and Cambrian rocks. The area covered by the reconnaissance map of southwestern Nevada and eastern California by Ball (1907, pl. 1) borders the quadrangle on the north. The first major contribution on the geology of the Panamint Butte area was by Hopper (1947, pl. 1), whose strip map from the Sierra Nevada to Death Valley covers the southern part of the Panamint Butte quadrangle and the Modoc district. Geologic Guidebook Number 1, Western Mojave desert and Death Valley region, by Wright and Troxell (1954), and the geologic map of California (Jennings, 1958, Death Valley sheet) are useful guides for the geology of the general region.

Other papers that deal with the geology of nearby areas in the Panamint Range or Panamint Valley include Gale (1915), who studied Panamint Basin, Murphy (1930, 1932), who mapped the area around the Panamint silver district, Maxson (1950), who made a physiographic study of the Panamint Range, Sears (1955), who mapped in the vicinity of Tucki Mountain, and Johnson (1957), who mapped part of the Manly Peak quadrangle.

Several papers resulting from the cooperative study of the Inyo County lead-silver-zinc deposits by the U. S.

Geological Survey and the California Division of Mines have been published of nearby districts. McAllister mapped the Ubehebe Peak quadrangle and adjacent Quartz Spring area (1952, 1955, 1956); MacKevett (1953) described the Santa Rosa mine; Merriam and Hall (1957) described the late Paleozoic stratigraphy of the southern Inyo Mountains; and Hall and MacKevett (1958, in press) mapped the Darwin quadrangle.

The writers wish to express their appreciation to the mine owners and operators for their cooperation in this study, especially to Robert Foreman, A. L. Foss, C. R. King, Mrs. Agnes Reid, Louis Rohr, and Tom Vignich. Matt Ryan of the National Park Service at Emigrant Station in the Death Valley National Monument and Mrs. Ryan extended many courtesies to the writers that are gratefully acknowledged. J. F. McAllister of the U. S. Geological Survey spent four days in the field with the writers and was of invaluable assistance with stratigraphic problems. All fossils were identified by paleontologists of the U. S. Geological Survey. Identifications were made by Jean M. Berdan, R. C. Douglass, Helen Duncan, J. Thomas Dutro, Jr., W. H. Haas, Kenneth E. Lohman, W. A. Oliver, Jr., Reuben J. Ross, Jr., W. J. Sando, and Ellis L. Yochelson.

GENERAL GEOLOGY

The Panamint Butte quadrangle is underlain by a sequence of metamorphic and sedimentary rocks of Precambrian(?) to Permian age that is intruded by quartz monzonite plutons of Jurassic(?) age and andesite porphyry dikes of Cretaceous(?) age. Late Cenozoic volcanic rocks and sedimentary deposits unconformably overlie this sequence (pl. 1). Late Precambrian(?) metamorphic rocks are limited to three small outcrops—two in the Panamint Range and one in Panamint Valley. Coarse-grained quartz-mica schist, quartzite, and biotite-hornblende gneiss are the predominant lithologic types. Paleozoic strata range in age from Middle(?) Cambrian to Permian in a conformable sequence approximately 14,000 feet thick. Silurian and older Paleozoic rocks, which are exposed only in the Panamint Range, consist mainly of dolomite and lesser quartzite, limestone, and shale. Devonian and younger Paleozoic rocks are mainly limestone, marble, and silty limestone, and they are abundantly exposed in both the Panamint and Argus Ranges.

The stratigraphy is described under 10 major lithologic sequences shown on the economic map (pl. 1). Table shows the formations that have been grouped in each major map unit. Formations have been shown only on the Modoc district map (pl. 2) and on detailed mine maps. The formation names used herein are the same as used by McAllister (1952) for the Lower Mississippian and older Paleozoic formations in the Quartz Spring area. The Lee Flat limestone was introduced by Hall and MacKevett (1958, p. 8) in the Darwin quadrangle. Nomenclature introduced by Merriam and Hall (1957) is used for the Pennsylvanian and Permian strata. Of the 10 major map units, the marble sequence, which consists predominantly of clean marble, is the most favorable for lead-silver deposits.

GNEISSIC SEQUENCE

The gneissic sequence includes all rocks that are metamorphosed to gneiss, schist, or coarse-grained quartzite. The sequence is sparsely exposed in the Panamint Range and in Panamint Valley at the souhtern border of the quadrangle where it extends southwest into the Maturango Peak quadrangle. The ages of rocks assigned to this sequence are not known, but they are probably both Precambrian and Cambrian.

Precambrian(?) rocks

Rocks of probable Precambrian age are limited to two small exposures in the Panamint Range and an isolated outcrop in Panamint Valley at the southern border of the quadrangle (pl. 1). Both of the exposures in the Panamint Range are beneath thrust faults. The southerly exposure in the Panamint Range 2 miles south of Nova Canyon consists of interbedded white, red, and reddish-brown quartzite, micaceous and limy quartzite, and minor dolomite in a section 700 feet thick. The northerly exposure 3 miles N. 57° W. of the Lemoigne mine consists of coarse-grained quartz-mica schist and light reddish-brown quartzite. Biotite-hornblende gneiss and mica schist crop out in the isolated hill in Panamint Valley at the south end of the quadrangle.

The assignment of a Precambrian age to these rocks is on the basis of similarity in lithology and degree of metamorphism to other Precambrian rocks in the Death Valley area. It is possible, though, that the northerly outcrop is contact metamorphosed clastic rocks of Early Cambrian age.

Cambrian(?) rocks

A gneissic sequence approximately 700 feet thick is exposed 1¼ miles west of the Lemoigne mine in a band 2 miles long; the base is not exposed. The sequence conformably underlies marble, dolomitic marble, and dark-gray limestone of probable Middle Cambrian age.

The sequence is a former shaly zone that has been contact metamorphosed to quartz-mica schist, gneiss, and quartzite. The gneiss and schist contain reddish garnets as much as one-fourth inch in diameter in a fine-grained groundmass of biotite, hornblende, muscovite, plagioclase, quartz, and calcite.

The age of the gneiss is probably Middle Cambrian. It conformably underlies dolomite that lithologically resembles the Racetrack dolomite of Middle and Late Cambrian age. It is believed to be about the same stratigraphic horizon as the Cadiz formation of Middle Cambrian age in the Nopah Range (Hazzard, 1937, p. 314).

DOLOMITE SEQUENCE

The dolomite sequence is present only in the Panamint Range in the Panamint Butte quadrangle. It consists pre-

Table 1. Stratigraphic section of the Panamint Butte quadrangle.

Age			Map units shown on Plate 1	Lithologic units	Thickness
CENOZOIC[1]	Quaternary	Recent	Younger alluvial deposits	Valley fill, fanglomerate, dune sand, and playa deposits	0–500
		Pleistocene		Dissected lacustrine deposits in Panamint Valley	
		Pleistocene and Pliocene	Rhyolitic tuff	Rhyolitic tuff, locally pumiceous	0–150
	Tertiary		Basalt	Olivine basalt, minor andesite, and agglomerate. Includes basalt and basaltic agglomerate intercalated with tilted fanglomerate	600+
			Older alluvium	Tilted fanglomerates and monolithologic breccias	5,000+
			—Unconformity—		
MESOZOIC		Cretaceous(?)	Andesite porphyry dikes	Altered andesite porphyry dikes	
		Jurassic(?)	Quartz monzonite	Biotite-hornblende quartz monzonite and leucocratic quartz monzonite	
PALEOZOIC		Permian	Silty limestone sequence	Owens Valley formation—gray thin- to medium-bedded silty limestone, calcarenite, shaly limestone, and siltstone	2,400+
		Permian and Pennsylvanian		Keeler Canyon formation—gray thin- to medium-bedded silty limestone interbedded with pure limestone	2,700±
	CARBONIFEROUS	Pennsylvanian(?) and Mississippian	Marble sequence	Lee Flat limestone—medium-bedded to massive white marble, light gray near base	900±
		Mississippian		Perdido formation—thin-bedded gray and brown limestone and chert	360±
				Tin Mountain limestone—gray thin- to medium-bedded limestone with minor chert; locally altered to marble	450±
		Devonian		Lost Burro formation—predominantly white and gray thin- to medium-bedded marble. Some dolomite and quartzite in lower part of formation	1,400±
		Devonian and Silurian	Dolomite sequence	Hidden Valley dolomite—light-gray medium- to thick-bedded dolomite	750±
		Ordovician		Ely Springs dolomite—dark- to light-gray dolomite, cherty at base	670
				Eureka quartzite—tan, gray, reddish-brown dolomite and white, gray, and red quartzite	300+
				Pogonip group—gray and brownish-gray medium- to thick-bedded dolomite	1,400±
		Cambrian		Nopah formation—medium- to thick-bedded gray and buff dolomite	1,500±
				Racetrack dolomite—medium- to thick-bedded gray limestone and buff and gray dolomite	1,600±
PRECAMBRIAN(?)		Cambrian(?) and Precambrian(?)	Gneissic sequence	Reddish brown quartzite, quartz mica schist, hornblende gneiss, and dolomite	700+

[1] Correlation of Cenozoic deposits is shown in table 1A.

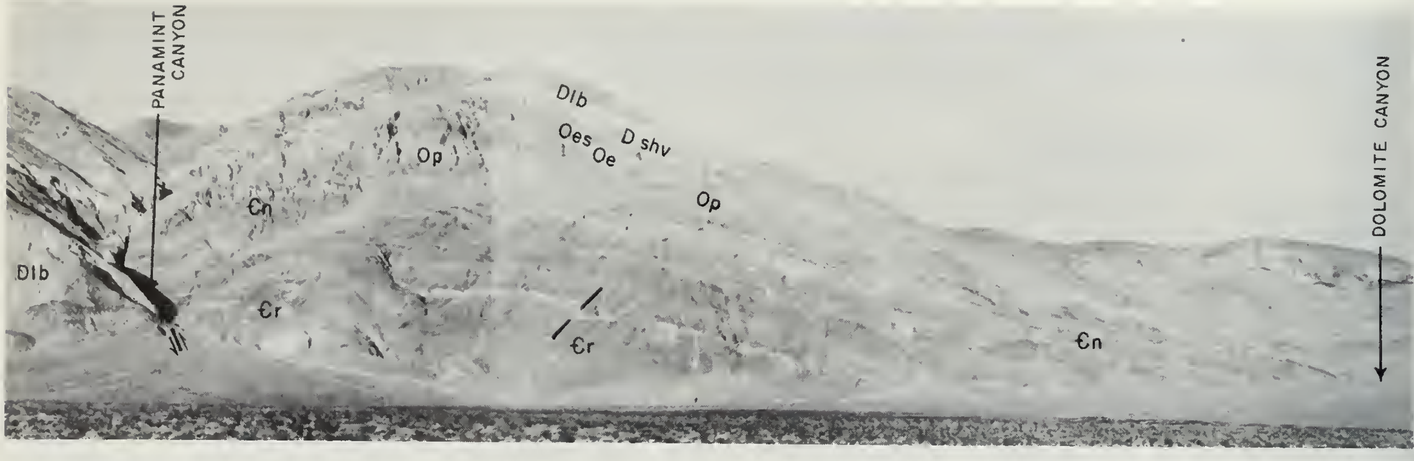

Photo 1. View of the west face of the Panamint Range north of Dolomite Canyon. The Racetrack dolomite (Ꞓr), Nopah formation (Ꞓn), and Pogonip group (Op) underlie the hill in the foreground. The hill in the distance is underlain by the Nopah formation, Pogonip group, Eureka quartzite (Oe), Ely Springs Dolomite (Oes), Hidden Valley dolomite (DShv), and Lost Burro formation (Dlb). The Lost Burro formation is faulted against Racetrack dolomite on the left side of the photograph.

dominantly of dolomite but includes some quartzite and limestone. Six formations ranging in age from Middle Cambrian to Early Devonian are combined in this sequence, which is approximately 6,200 feet thick. They are the Racetrack dolomite and Nopah formation of Cambrian age; the Pogonip group, Eureka quartzite, and Ely Springs dolomite of Ordovician age; and the Hidden Valley dolomite of Silurian and Early Devonian age.

Cambrian system

Ten square miles of the Panamint Butte quadrangle is underlain by rocks considered to be of Cambrian age by the writers, but no fossils have been found to date to verify this assignment. The writers feel that the assignment to the Cambrian system without query is justified because of lithologic similarity to Cambrian rocks described from nearby areas by McAllister (1952, p. 8-9) and because of stratigraphic position below fossiliferous Lower Ordovician rocks of the Pogonip group on the north side of Dolomite Canyon.

Cambrian rocks are exposed at the base of the west side of the Panamint Range on the north side of Dolomite Canyon and in the vicinity of the Lemoigne mine (pl. 1). The Cambrian rocks on the north side of Dolomite Canyon are divided into two formations—the Racetrack dolomite of Middle and Late Cambrian age and the Nopah formation of Late Cambrian age (photo 1). They lie conformably below fossiliferous beds of the Pogonip group of Early Ordovician age. The Cambrian rocks at the Lemoigne mine have not been differentiated into formations as they are in a thrust sheet and cannot be tied into the stratigraphic section, but most of the section lithologically resembles the Racetrack dolomite.

Racetrack dolomite

Dolomite that can definitely be assigned to the Racetrack dolomite in the Panamint Butte quadrangle is restricted to the base of the west side of the Panamint Range between Dolomite and Panamint Canyons (photo 1). Approximately 1,600 feet of medium-bedded buff and gray dolomite and interbedded gray limestone compose the section. The base of the formation is not exposed. Most of the dolomite sequence in the vicinity of the Lemoigne mine lithologically resembles the Racetrack dolomite, but it is in a thrust sheet and the assignment is uncertain. The dolomite sequence here consists of about 500 feet of white marble, dolomitic marble, and thinly bedded dark-gray limestone in the lower part. The upper part is about 2,000 feet thick and consists predominantly of thin- to medium-bedded dark-gray dolomite and some shale beds mostly less than 25 feet thick.

No fossils were found in the Racetrack dolomite within the quadrangle. At the type locality in the Quartz Spring area McAllister (1952, p. 9) considered it Middle(?) Cambrian on the basis of stratigraphic position conformably under the fossiliferous Nopah formation of Late Cambrian age. The U. S. Geological Survey now assigns the Racetrack a Middle and Late Cambrian age.

Nopah formation

The Nopah formation crops out on the west side of the Panamint Range between Dolomite and Panamint Canyons conformably overlying the Racetrack dolomite (photo 1) and on the hill half a mile northwest of the Big Four mine (pl. 1). The formation is 1,500 feet thick on the ridge 1.6 miles north of the mouth of Dolomite Canyon. The lower contact is marked by a sharp change in color and lithology from a brown-weathering, thinly bedded limestone, shale, and siltstone basal member to dark-gray, medium-bedded limestone and dolomite in the Racetrack dolomite.

The Nopah formation consists almost entirely of Dolomite except for a basal shale and limestone unit 225 feet thick. The basal unit consists of thinly bedded gray and brownish-gray limestone, olive-green shale, and brown-weathering siltstone and cherty limestone. It makes a conspicuous marker horizon because of its dark-brown color on weathered surfaces. Above the basal unit is thickly bedded gray and buff dolomite in bands 20 to several hundred feet thick. Dark-gray dolomite is most abundant in the lower part of the formation and buff-colored dolomite in the upper part.

The Nopah formation is Late Cambrian in age. No fossils were found in the Panamint Butte quadrangle, but it lies conformably beneath fossiliferous strata of Early Ordovician age. McAllister (1952, p. 9) found trilobites and primitive brachiopods in the basal member of the Nopah formation that were identified by G. Arthur Cooper and A. R. Palmer as Late Cambrian in age.

Ordovician system

Pogonip group

Exposures of the Pogonip group are chiefly restricted to the east-central part of the quadrangle in the vicinity of Dolomite Canyon (photo 1). Other exposures are at the Big Four mine and near the eastern border of the quadrangle in Nova Canyon.

The Pogonip is 1,260 and 1,400 feet thick in two measured sections between Dolomite and Panamint Canyons. It conformably overlies the Nopah formation near the foot of the Panamint Range on the north side of Dolomite Canyon. The contact is gradational and is marked by a change from thickly bedded, dark-gray and buff dolomite that is conspicuously banded in the Nopah formation to a thin- to medium-bedded dolomite and limestone in the Pogonip group that weathers to a brownish-gray color. The Pogonip group is undifferentiated in our mapping.

The Pogonip consists of fine-grained, medium-gray to buff, medium-bedded dolomite and lesser limestone. The dolomite weathers brownish-gray. Several brown and reddish-brown beds as much as 135 feet thick, referred to as crepe beds, are prominent marker beds in the upper part of the group. A zone of large gastropods and algae are almost invariably present above the crepe beds in the upper part of the Pogonip.

The Pogonip is Early and Middle(?) Ordovician in age. The upper part of the Pogonip contains abundant gastropods [*Palliseria longwelli* (Kirk)] identified by Ellis L. Yochelson (written communication, 1957) and *Receptaculites* sp. cf. *R. elongatus* Walcott identified by Jean M. Berdan (written communication, 1957).

Eureka quartzite

The Eureka quartzite crops out on the west flank of the Panamint Range in the vicinity of Dolomite Canyon, on the steep slope 4½ miles N. 8° E. of BM 2081 on Highway 190, and in the basin 1 mile N. 22° E. of the Big Four mine (pl. 1). It is also exposed in discontinuous patches in a jumbled section 1¼ miles S. 26° E. of Towne Pass. The most easily accessible complete section is on the south side of Dolomite Canyon 2¾ miles N. 31° E. of BM 2081.

The Eureka is 285 feet thick in the measured section on the south side of Dolomite Canyon. The contact with the underlying Pogonip group is gradational and was placed at a color change from brownish-gray dolomite that is slightly sandy in the Pogonip to pinkish or reddish sandy dolomite with some thin quartzite beds in the basal Eureka.

The Eureka is much more dolomitic than in nearby areas described by McAllister (1952, p. 12) or Hall and MacKevett (1958, p. 7). It consists of two units—a lower thinly bedded shaly and dolomitic unit and an upper quartzitic unit. The lower unit contains interbedded light-brown, pink, and reddish-gray silty and sandy dolomite, sandy limestone, shale, and argillaceous quartzite. The upper unit is almost entirely white, reddish-gray, and dark-red quartzite about 125 feet thick.

No fossils were found in the Eureka, but, based on stratigraphic position, it is Middle to Late(?) Ordovician in age. It conformably overlies the Pogonip group of Early and Middle(?) Ordovician age and the basal part of the overlying Ely Springs dolomite contains fossils of Late Ordovician age.

Ely Springs dolomite

The Ely Springs dolomite crops out on Lake Hill, on the west flank of the Panamint Range near Dolomite Canyon, and near the eastern edge of the quadrangle 1½ miles S. 20° E. of Towne Pass. It is 670 feet thick in a measured section south of Dolomite Canyon, 2.55 miles N. 31° E. of BM 2081. The contact with the underlying Eureka quartzite is sharp and conformable.

The Ely Springs consists of a lower unit of dark-gray cherty dolomite and an upper unit of light-gray dolomite. The lower unit consists of medium-bedded, dark-gray dolomite with abundant dark-gray chert lenses and nodules. The dolomite becomes progressively lighter in color upward in the section. The upper unit is light- and medium-gray, thickly bedded dolomite, and chert is almost completely lacking. A band of dark-gray dolomite is usually present at the top of the upper unit. The formation is of Late Ordovician age based on fossils collected from near the bottom of the formation and studied by Reuben J. Ross, Jr., (written communication, 1957) and W. H. Haas (written communication, 1957) of the U. S. Geological Survey. It contains conodonts, rhynchonellid brachiopods, *Resserella* sp., *Lepidocyclus*, and cephalopod *Armenoceras*.

Silurian and Devonian systems

Hidden Valley dolomite

The Hidden Valley dolomite crops out on the west flank of the Panamint Range between Panamint and Dolomite Canyons and at the head of Dolomite Canyon. The most continuous exposure is a band about 1.4 miles long 4½ miles N. 12° E. of BM 2081 (photo 1). A small but more accessible exposure is 1 mile S. 35° E. of Towne Pass. The formation is about 400 feet thick on the west face of the Panamint Range 4½ miles N. 12° E. of BM 2081. This is considerably thinner than the 1,365 feet at the type locality in the Quartz Spring area (McAllister, 1952, p. 15) or the plus 1,000 feet in the Darwin quadrangle (Hall and MacKevett, 1958, p. 7).

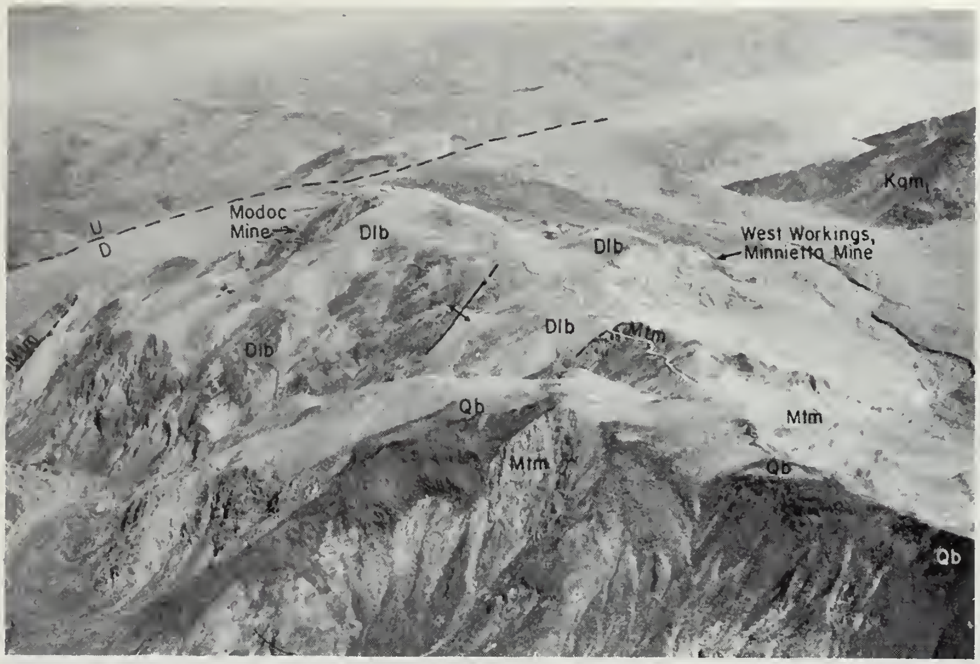

Photo 2. Aerial view of Lookout Mountain showing the distribution of the Lost Burro formation (Dlb) and the Tin Mountain limestone (Mtm). The axis of an anticlinal structure is shown in the center of the photograph. Isolated outcrops of olivine basalt (Qb) overlie Tin Mountain limestone in the foreground; the dark patch in the upper righthand corner is biotite-hornblende-quartz monzonite (Kqm_1). Camera facing southeast.

The Hidden Valley uniformly is a gray to light-gray, medium- to thick-bedded dolomite. Sparse white vitreous quartzite beds mostly less than 3 feet thick are interbedded locally in the dolomite. In places light-gray chert nodules that weather brown are present near the base of the formation. They probably are silicified colonial corals.

No identifiable fossils were found in the Hidden Valley dolomite within the quadrangle. In the Quartz Spring area McAllister (1952, p. 16-17) dated the formation as of Silurian and Early Devonian age.

MARBLE SEQUENCE

The marble sequence is present in both the Panamint and Argus Ranges. It consists predominantly of clean marble of Devonian and Mississippian ages and is the principal host rock for the lead-silver deposits. The sequence is about 3,100 feet thick and includes the Lost Burro formation of Devonian age, the Tin Mountain limestone and Perdido formation of Mississippian age, and the Lee Flat limestone of Mississippian and Pennsylvanian(?) age.

Devonian system

Lost Burro formation

The Lost Burro formation crops out in both the Argus and Panamint Ranges. It is the oldest rock type in the northern Argus Range and is the predominant rock type at Lookout Mountain between the Modoc and Minnietta mines in the Modoc district (pl. 2, photo 2). It crops out high in the Panamint Range between Panamint and Dolomite Canyons and at the foot of the range on the north side of Panamint Canyon (fig. 2A).

The formation is 1,170 to 1,500 feet thick in the Panamint Range. The thickness in the Argus Range is not known because of the large amount of faulting and folding in the Modoc district. It is overlain conformably by the Tin Mountain limestone of Early Mississippian age. The contact is sharp and is marked by color change and in places by a sandy bed at the top of the formation.

The Lost Burro formation consists predominantly of dolomite in the lower part, and limestone, in large part recrystallized to marble, and some dolomite in the upper part. The lower dolomitic part, which is 200 to 300 feet thick, is exposed only in the Panamint Range. It consists of interbedded light- and dark-gray dolomite that has a banded appearance. The middle and upper parts are mainly banded, very light gray marble, gray and bluish-gray, thin- to medium-bedded limestone, and some tan sandy dolomite. The gray limestone bands commonly contain concentric cherty structures of poorly preserved stromatoporoids.

The Lost Burro formation is Middle and Late Devonian in age. Dark limestones in the middle part of the formation contain abundant stromatoporoids, including *Amphipora,* which are characteristic of the Middle Devonian of the Great Basin (for example see Nolan and others, 1956, p. 50). Devonian rocks had not previously been recognized in the northern Argus Range. Four collections of *Amphipora* sp. were collected from the Modoc and Minnietta mine areas and were studied by W. A. Oliver, Jr. (written communication, 1959) of the U. S. Geological Survey. He reports:

> "The age of the four *Amphipora* collections is most likely Middle or Late Devonian. The range of this stromatoporoid genus is variously given, but Silurian and post-Devonian occurrences are not well authenticated anywhere, and none are known from North America. At the present time, *Amphipora* is considered a good index of Middle to early Late Devonian age."

Photo 3. This photograph shows the stratigraphic section of the Modoc district ranging in age from Devonian to Permian. View is north along a ridge north of the Defense mine road and 3.4 miles east of the southwest corner of the quadrangle. Included are the Lost Burro formation (Dlb), Tin Mountain limestone (Mtm), Perdido formation (Mp), Lee Flat limestone (ℙMlf), and Keeler Canyon formation (Pℙkc).

Mississippian system

Tin Mountain limestone

The Tin Mountain limestone is present in the Panamint Butte quadrangle in both the Argus and Panamint Ranges. It crops out for about 1½ miles along the axis of a major anticline in the Argus Range (pl. 2). In the Panamint Range it is most abundant near the foot of the range on the north side of Panamint Canyon and near the crest of the range between Panamint and Dolomite Canyons. The most easily accessible fossiliferous locality is three-quarters of a mile S. 65° E. of Towne Pass, but the top of the formation is eroded.

The Tin Mountain limestone is 380 feet thick in a measured section in the Argus Range along a ridge 3.4 miles east of the southwest corner of the Panamint Butte quadrangle (photo 3). In the Panamint Range it is aboute 450 feet thick.

The Tin Mountain limestone is a thin- to medium-bedded, fine-grained, gray limestone that locally contains brown chert lenses and nodules. In the Modoc district much of the limestone is bleached and recrystalized to marble and is difficult to distinguish from marble of the Lost Burro formation.

The Tin Mountain is Early Mississippian in age. It is the most fossiliferous formation in the Paleozoic sequence. *Syringopora surcularia* Girty is particularly characteristic of the formation. Helen Duncan, J. T. Dutro, Jr., W. J. Sando, and Ellis L. Yochelson of the U. S. Geological Survey identified 55 genera or species of brachiopods, bryozoans, cephalopods, corals, gastropods, pelecypods, and trilobites. W. J. Sando (Written communication, 1959) reports as follows:

"The coral assemblage is very similar to that of the middle and upper Lodgepole limestone (of the Madison group) of Montana, Wyoming, and Utah. The Lodgepole is of Early Mississippian age."

J. Thomas Dutro, Jr., and Ellis L. Yochelson (Written communication, 1959) report about the Tin Mountain fauna:

"The fauna is clearly related to that found in the upper part of the Lodgepole in the northern Rocky Mountains."

Perdido formation

Exposures of the Perdido formation are present in both the Panamint and Argus Ranges. It is present in the Modoc district in the Argus Range as a band around the nose of the north-plunging anticline (pl. 2), and it is present near the crest of the Panamint Range between Panamint and Dolomite Canyons. The formation is about 360 feet thick in the Argus Range and 350 feet thick in the Panamint Range.

The Perdido formation is a dark-brown weathering, cliff-forming unit that makes a conspicuous horizon marker. It consists of thinly bedded, fine-grained, gray limestone with abundant thin, brown-weathering beds, lenses, and veinlets of chert. Near intrusive contacts the thinly bedded rocks are commonly contorted and are altered to calc-hornfels and tactite.

Few fossils were found except for crinoid columnals and sparse poorly preserved solitary corals. On the basis of stratigraphic position it is younger than the Tin Mountain limestone of Early Mississippian age and older than the basal part of the Keeler Canyon formation of Pennsylvanian and early Permian age. On the basis of fossil evidence in the Quartz Spring area, McAllister (1952, p. 24-25) reports a Mississippian age, ranging possibly from Osage or late Kinderhook into Chester.

Mississippian and Pennsylvanian(?) systems

Lee Flat limestone

White marble of the Lee Flat limestone crops out conspicuously in both the Argus and Panamint Ranges. In the Argus Range it is present around the nose of the north-plunging anticline in the Modoc district (pl. 2), and it forms all the prominent thick white marble bands north of Dolomite Canyon on the west face of the Panamint Range (see photo 7). The formation is about 650 feet thick.

The Lee Flat limestone consists entirely of clean white to very light gray marble with an average grain size of 1 to 2 mm. Beds commonly are less than 1 foot thick, but the uniform white color gives the formation a massive appearance. Partial dolomitization of the marble is common in the Argus Range but is not common in the Panamint Range. An analysis of the marble is given under "Limestone," page 38.

Crinoidal columnals are the only fossils found in the Lee Flat limestone. On the basis of stratigraphic position it is considered Mississippian and Pennsylvanian(?) in age (Hall and MacKevett, 1958, p. 9).

SILTY LIMESTONE SEQUENCE

The silty limestone sequence is present in both the Argus and Panamint Ranges (pl. 1). It is approximately 5,000 feet thick and consists predominantly of thinly bedded silty and sandy limestone, but includes some shale, siltstone, and limestone conglomerate and breccia. Combined in this sequence are the Keeler Canyon formation of Pennsylvanian and Permian age and the Owens Valley formation of Permian age.

Pennsylvanian and Permian systems

Keeler Canyon formation

The Keeler Canyon is the thickest and most widely exposed Paleozoic formation in the quadrangle. It crops out as a wide band around the nose of the Argus Range anticline (pl. 2). In the Panamint Range it is the thinly banded bluish-gray and white limestone that is so abundant on the west face of the range north of State Highway 190 (see photo 7), and it underlies the Lemoigne thrust in the northeast part of the quadrangle (pl. 1).

The thickness ranges widely over short distances. A measured section along the ridge 3.3 miles N. 81° E. of the southwest corner of the quadrangle is 1,825 feet thick. It is 2,600 feet thick on the west flank of the Argus Range anticline about 2½ miles to the west (pl. 2). In the Panamint Range it is 2,685 feet thick on the southeast side of Panamint Canyon on the west side of hill VABM 7287, but the top of the formation is not exposed (pl. 1). The thickness also ranges widely in adjacent areas. It is 4,000 feet thick in the Darwin Hills (Hall and MacKevett, 1958, p. 9) and 1,300 to 2,500 feet thick at the type locality in the southern Inyo Mountains (Merriam and Hall, 1957, p. 5). The Keeler Canyon formation is overlain conformably by the Owens Valley formation of Permian age. The contact is transitional and, in general, is placed at the inception of abundant siltstone, lenses of pure limestone or limestone breccia, and cross-bedded calcarenite in the overlying formation.

The formation consists of thinly bedded bluish-gray silty and sandy limestone, clean limestone, limestone breccia, and locally siltstone. In the Argus Range the general aspect of the formation is a uniform bluish-gray color of thinly interstratified beds. The lower part consists of thinly bedded gray and bluish-gray silty limestone that contains round chert nodules ¼ to 2 inches in diameter and is referred to as the "Golfball" horizon (Merriam and Hall, 1957, p. 5). The upper part of the formation is more shaly and consists of black siliceous shale, pink shale, and some limestone conglomerate and breccia interbedded in predominant shaly limestone.

In the Panamint Range the Keeler Canyon has a general striped appearance of bluish-gray limestone and thin white or very light-gray bands of marble (see photo 7). The limestone, particularly in the middle part of the formation, is much purer than that to the west in the Argus Range or Darwin quadrangle (Hall and MacKevett, 1958, p. 9) and lacks abundant fusulinids found elsewhere in the formation.

The Keeler Canyon formation ranges in age from Pennsylvanian to early Permian. Fusulinids are the most abundant fauna in the Argus Range, but were found only in the upper part of the formation in the Panamint Range, where bryozoans and brachiopods are the most abundant. Fusulinids were found within 100 feet of the base of the formation. R. C. Douglass (written communication, 1958) reports on a collection from this zone as follows:

f 12373

> Field identification: base of Keeler Canyon formation, S. 16° E., 5.75 miles from Panamint Springs at an altitude of 3,680 feet.
>
> *Climacammina* sp.
> *Fusulinella* sp.

"This sample contains only a few recrystallized specimens of fusulines. These are probably assignable to *Fusulinella*, although all the characters cannot be determined. Middle Pennsylvanian (early Des Moines) is suggested."

The upper part of the Keeler Canyon is early Permian (Wolfcamp) in age. *Triticites* is the characteristic fusulinid although *Pseudofusulinella*, *Schwagerina*, and primitive forms of *Parafusulina* are common genera. Douglass (written communication, 1958) states this fauna is of early Permian age, probably middle to late Wolfcamp equivalent.

The lowest fossils sufficiently well preserved to be collected in the Panamint Range are about 1,000 feet above the base of the formation. They are described by J. T. Dutro, Jr., of the U. S. Geological Survey as follows:

f 18312-PC

> Keeler Canyon formation. 2,200 feet N. 48° W. of VABM 7287 at an altitude of 6,540 feet.
>
> orthotetid brachiopod, indet.
> *Mesolobus*? sp.
> *Lissochonetes*? sp.

"This collection is most likely of Middle Pennsylvanian age. Only the relatively poor preservation of material prevents a more positive assignment."

Bryozoans were collected 2,100 feet above the base of the formation on the northwest side of hill VABM 7287. They were identified as *Rhomboporella* by Helen Duncan (written communication, 1959), who states that this genus ranges from lower Middle Pennsylvanian into the Permian.

Permian system

Owens Valley formation

The Owens Valley formation crops out in the Argus Range in the northern part of the silty limestone sequence where it is intruded by abundant andesite porphyry dikes about 1½ miles southwest of Panamint Springs. The formation is about 2,400 feet thick, but the upper part is not present. It consists of interbedded gray thin- to medium-bedded silty limestone, calcarenite, siltstone, and lenses of pure limestone and limestone breccia. Only the lower limestone member described by Hall and MacKevett (1958, p. 10) from the Darwin Hills is present.

Fusulinids are abundant in parts of the Owens Valley formation, and solitary corals, bryozoa, and gastropods are present locally. The fusulinids are considered to be Early Permian (late Wolfcamp equivalents) by R. C. Douglass (written communication, 1958).

PLUTONIC ROCKS OF MESOZOIC AGE

Plutonic rocks are exposed in the northern and southwestern parts of the quadrangle over an area of 14 square miles (pl. 1). Two lithologic types—biotite-hornblende quartz monzonite and leucocratic quartz monzonite—predominate in the quartz monzonite unit. Locally granodiorite and syenodiorite constitute hybrid border zones, and small bodies of leucogranite and aplite are common diaschistic differentiates. Altered andesite porphyry dikes intrude the Paleozoic rocks and quartz monzonite in the Argus Range.

Biotite-hornblende quartz monzonite

Biotite-hornblende quartz monzonite crops out in the northern part of the quadrangle in the southeastern end of the batholith of Hunter Mountain, which was described previously by McAllister (1955, p. 14; 1956) and by Hall and MacKevett (1958, p. 11). It is present in the northern part of the Argus Range in a stock 1 mile west of Panamint Springs (pl. 1) and in a pluton extending from the southern part of the Modoc district south to Maturango Peak (pl. 2).

The biotite-hornblende quartz monzonite is a medium-grained, light-gray rock that has a dark speckled appearance produced by disseminated biotite and hornblende. The texture ranges from equigranular to porphyritic, with 10 to 20 percent phenocrysts of pink feldspar as much as 1 cm in diameter. Essential minerals include potassium feldspar, plagioclase, and quartz, and varietal minerals biotite and hornblende. The plagioclase is calcic oligoclase or andesine and it is usually strongly zoned; plagioclase exceeds the average potassium feldspar content by about 10 percent. The potassium feldspar is microperthite, and some of it has microcline twinning. Quartz ranges from 5 to 20 percent but usually constitutes about 15 percent of the rock. Mafic minerals average about 13 percent of the rock; hornblende generally is the more abundant. Accessory minerals include apatite, magnetite, sphene, and zircon.

Leucocratic quartz monzonite

Two small stocks of leucocratic quartz monzonite crop out in the Argus Range in the southwestern part of the quadrangle—one is in Osborne Canyon north of the Surprise mine and the other is the east end of the Zinc Hill stock along the western margin of the quadrangle 3½ miles north of the southwest corner (pl. 1). It is a pinkish-gray, coarse-grained hypidiomorphic-granular rock that is commonly porphyritic.

Essential minerals are orthoclase, plagioclase, and quartz. Mafic minerals at most places constitute less than 5 percent of the rock. Plagioclase and orthoclase each constitute 30 to 40 percent of the rock. Orthoclase is microperthite and commonly is present as phenocrysts as much as 1½ cm. in diameter. Plagioclase is principally oligoclase and ranges in composition from An_{19} to An_{33}. Quartz averages about 17 percent of the rock. Biotite, which is mostly altered to chlorite, is the predominant mafic mineral. Apatite, magnetite, sphene, and zircon are common accessory minerals.

Age

The granitoid rocks in the Panamint Butte quadrangle intrude Permian strata and are overlain by late Cenozoic rocks. Two intrusions of biotite-hornblends-quartz monzonite in the Argus Range were dated by the lead-alpha and potassium-argon methods as 180 million years (T. W. Stern and H. H. Thomas, written communication, 1961). Thus they are very Early Jurassic (Kulp, p. 1111, 1961).

Two small stocks of leucocratic quartz monzonite exposed in the Argus Range are presumably the same age as the biotite-hornblends-quartz monzonite plutons, even though age determinations were made only on samples of the latter.

Andesite porphyry dikes

A swarm of andesite porphyry dikes striking in general N. 70° W. intrudes the Owens Valley formation 1½ miles southwest of Panamint Springs (pl. 1). One prominent dike half a mile long cuts across quartz monozonite as well as Paleozoic rocks in the southern part of the Modoc district (pl. 2). This swarm of dikes extends from the northern Argus Range at least 30 miles northwest to the southern Inyo Mountains. The dikes are as much as 1 mile long and are mostly less than 10 feet thick. Some of the mineral deposits are localized adjacent to them, for example at the Minnietta and Little Mack mines in the Modoc district.

Photo 4. Concordant lenses of monolithologic breccias from Paleozoic dolomite interbedded in Pliocene(?) Nova formation of Hopper (1947) 1½ miles southeast of Towne Pass.

The dikes are greenish-gray on fresh surfaces and weather brownish. They invariably are highly altered and consist of phenocrysts of plagioclase with saussuritic alteration in a fine-grained groundmass of plagioclase, hornblends, clinozoisite, chlorite, and calcite. Plagioclase is mainly albite, but relict andesine is present locally.

The dikes intrude quartz monzonite but are older than the lead-silver deposits. They are considered Cretaceous (?) in age.

CENOZOIC DEPOSITS

The Cenozoic deposits are subdivided as follows on the economic map (pl. 1): (1) older alluvium; (2) basalt; (3) rhyolitic tuff; and (4) untilted younger alluvial deposits. The first three units are all noticeably tilted. Their ages range from probable late Pliocene to middle Pleistocene. Both the older alluvium and basalt contain at least two mappable units of different ages, and they overlap each other in age. Therefore the descriptions of the Cenozoic deposits that follow can not be treated strictly chronologically. The correlation of the units is given in table 1A.

Older alluvium

On the economic map (pl. 1) two tilted fanglomerates are lumped under older alluvium. A thoroughly indurated fanglomerate of Pliocene(?) age that is tilted to dips of 25° to 40° E. is overlain with an angular unconformity by a Pleistocene fanglomerate that has been tilted to dips of 5° to 15° E. Both fanglomerates were included in the Nova formation by Hopper (1947).

The oldest fanglomerate is extensively exposed on the west side of the Panamint Range in the southeastern part of the quadrangle. There are good exposures of the fanglomerate along State Highway 190 at altitudes of about 4,000 feet and easily accessible outcrops 1½ miles southeast of Towne Pass, where it lies with an angular unconformity upon shattered Paleozoic rocks of Cambrian to Mississippian age. The fanglomerate consists of 3,500 feet of reddish-orange and light-brown conglomerate, beds of reddish or tan clay and silt, and abundant monolithologic breccias of dolomite, quartzite, and phyllite. Basaltic and andesitic flows and agglomerate are interbedded in the older fanglomerate, but not in the younger. The fanglomerate consists predominantly of rounded pebbles and cobbles of gneiss, schist, dolomite, and quartzite of Precambrian and Paleozoic ages that had their source toward the southeast. In general clasts of Paleozoic rocks are most abundant in the lower part of the fanglomerate and clasts of Precambrian rocks in the upper part.

Monolithologic breccias are present only in the older tilted fanglomerate. They are abundant and well exposed 1½ miles southeast of Towne Pass (photo 4). The breccias are from dolomite and quartzite formations of Paleozoic age and have a local source, whereas most of the clasts in the fanglomerate came from Precambrian terrane farther to the southeast. Individual breccia lenses are as much as 250 feet thick and 2 miles across. Their length is not exposed. The Paleozoic source rock for the

Table 1A. Correlation of lithologic types combined in the four economic map units of Cenozoic deposits.

Age	Older alluvium	Basalt	Rhyolitic tuff	Younger alluvial deposits
Recent				Alluvium including fanglomerate, playa deposits, and sand dune deposits.
Pleistocene	Old fanglomerate	Olivine basalt		Lake beds in Panamint Valley
Pleistocene / Pliocene	Nova formation of Hopper (1947). Includes fanglomerate and monolithologic breccias.	Basalt and andesite agglomerate and flows. Interbedded in the Nova formation of Hopper (1947) and underlies olivine basalt in the Argus Range.	Rhyolitic tuff	

monolithologic breccias is in a thrust plate on which the dolomitic and quartzitic rocks were completely shattered so that there are few blocks more than a foot in diameter (photo 5).. This shattered Paleozoic terrane provided extensive areas of talus and loose rock. During a period of steep topography and wet climate of the late Pliocene(?) this debris slid by gravity onto the fanglomerate, forming the concordant lenses of monolithologic breccia.

The overlying fanglomerate tilted 5° to 15° E. is younger than the extensive capping of olivine basalt. It is less indurated than the underlying fanglomerate, but contains pebbles and cobbles of about the same size, shape, and composition.

Basalt

Within the area shown as basalt on the economic map (pl. 1) are grouped basaltic and andesitic flows and agglomerate interbedded in the Nova formation of Hopper (1947), agglomerate underlying the capping olivine basalt in the Argus Range, and the younger extensive olivine basalt flows that form the extensive basalt capping in the Death Valley to Owens Valley area (table 1A). The basaltic and andesitic flows and agglomerate interbedded in the Nova formation of Hopper (1947) are well exposed along State Highway 190 south and southwest of Towne Pass (pl. 1). They have a maximum thickness of about 400 feet and consist mainly of gray, green, red, and purple flows of andesite and basalt and some beds of agglomerate interbedded in the fanglomerate. The adjacent fanglomerate is altered red for several hundred feet from the volcanic rocks. Conspicuous amygdaloidal structures are common in the upper parts of the flows.

Red basaltic and andesitic agglomerate as much as 200 feet thick underlies olivine basalt in the Argus Range. The agglomerate is the same composition as the flows interbedded in the Nova formation and is considered to be the same age. These rocks are correlated with the volcanics of Pliocene(?) age in the Darwin quadrangle (Hall and MacKevett, 1958, table 2, p. 13).

Extensive flows of olivine basalt cap much of the east flank of the Panamint Range north of Towne Pass and parts of the Argus Range north of Osborne Canyon and on Ash Hill (pl. 1). These flows have an aggregate thickness of as much as 400 feet in Rainbow Canyon. They correlate with the olivine basalt flows of Pleistocene age in the Darwin quadrangle (Hall and MacKevett, 1958, table 2, p. 13).

Rhyolitic tuff

Rhyolitic tuff is present only in the Argus Range between Ash Hill and Panamint Springs as remnants of a former more extensive welded tuff. It is well exposed in Ash Hill beneath a flow of olivine basalt. The rhyolitic tuff is white, reddish-buff, or buff in color and ranges up to 150 feet in thickness. It contains angular fragments of buff and gray rhyolite in a glassy fine-grained tuffaceous groundmass. Phenocrysts of sanidine, quartz, plagioclase, tridymite, biotite, and oxyhornblende are present in the glassy groundmass. The age of the rhyolitic tuff is probably late Pliocene or early Pleistocene.

Younger alluvial deposits

Grouped in this unit are untilted Pleistocene lake beds in Panamint Valley, elevated fans of late Pleistocene age, and Recent alluvial fans, playa deposits, and dune sands. They cover about a third of the quadrangle. Remnants of elevated lacustrine deposits are exposed in Panamint Valley at the south end of the quadrangle in secs. 21, 27, and 28, T. 19 S., R. 43 E.; as two isolated hills half a mile east of Panamint Springs; and on the east side of Pana-

Photo 5. Shattered Eureka quartzite (light) and Ely Springs dolomite (dark) in a thrust plate 1.7 miles S. 20° E. of Towne Pass. The shattered Paleozoic rocks provided the local source of debris for the monolithologic breccias, which slid by gravity during the late Pliocene(?).

mint Valley half a mile south of State Highway 190 at an altitude of 2,200 feet. Diatoms and tiny gastropods were collected by the writers from lake beds half a mile east of Panamint Springs. Kenneth E. Lohman (written communication, 1957) studied the diatoms and reports:

"This assemblage of nonmarine diatoms is indicative of deposition in a fairly saline lake which was probably similar in this respect to the one now represented by the Darwin Wash lake beds. The dominance of attached bottom living forms indicates that the lake was either shallow or that the water was very clear. Diatoms are photosynthetic organisms and require abundant light, which could hardly be obtained on the bottom of either a turbid or very deep lake. The frequent occurrence of *Denticula thermalis* in this assemblage suggests that hot springs may have been active somewhere in the vicinity.

"Although only 32 percent of the diatoms in this assemblage also occur in the Darwin Wash lake beds (Lohman's report MD 56-22 dated 1954), the same age assignment of middle to late Pleistocene is the most reasonable * * *."

Untilted or only slightly tilted elevated dissected fans interfinger with the lake beds in Panamint Valley at the south end of the quadrangle. They also are present in the Panamint Range as remnants from reworked older fans, and in Panamint Valley on the southeast side of Ash Hill. The fans are the same age as the lake beds, dated as middle to late Pleistocene by Lohman.

Undisturbed Quaternary deposits consist of extensive alluvial fan material along the margin of Panamint Valley, playa deposits in the floor of the valley, and dune sand at the north end of Panamint Valley.

STRUCTURE

The rocks in the Panamint Butte quadrangle have been affected by three periods of deformation. The earliest formed broad open folds and major thrust and strike-slip faults by approximately east-west compressional stresses during the early Mesozoic. Both the Argus and Panamint Ranges were deformed into broad north- to N. 20° W.-trending anticlines. In the Panamint Range thrust faults accompanied the folding of the Paleozoic strata. The second period of deformation was caused by forcible intrusion of quartz monzonite batholiths and stocks of Jurassic (?) age, which intruded and deformed both the broad folds and the thrust faults. The intrusions were followed by a long period of erosion until the late Cenozoic when extensive regional warps and accompanying normal and strike-slip faults formed the present basin and range topography.

No major unconformities or hiatuses are recognized in the Paleozoic section. However, the Upper Ordovician and Silurian strata are thinner than sections described in the adjacent Ubehebe Peak and Darwin quadrangles (McAllister, 1956; Hall and MacKevett, 1958), and it is possible that disconformities in this part of the section may be unrecognized. Hopper (1947, p. 408) described an unconformity at the base of dolomite and limestone of Middle(?) Devonian age near the southeast corner of the Panamint Butte quadrangle apparently because of misinterpretation of the geology. He described 1,000 feet of Devonian conglomerate overlying Silurian(?) dolomitic limestone without angular discordance. The base map available to Hopper was poor so the writers could not be certain they were at the same places he described, but the conglomerate must be the basal part of the older alluvium east of Towne Pass (pl. 1). This is a well-consolidated fanglomerate that rests with only minor angular discordance upon a highly irregular surface cut across Paleozoic strata of Cambrian(?) to Mississippian age. This older alluvium contains abundant monolithologic breccias derived from carbonate rocks of Paleozoic age, and it is probable that one of these breccias forms the limestone and dolomite 300 feet thick that he described overlying the conglomerate.

Three major angular unconformities are recognized in the Panamint Range. One truncates deformed Paleozoic strata and Mesozoic instrusive rocks and lies under a tilted Pliocene(?) fanglomerate. A second major unconformity of probable middle Pleistocene age truncates the Pliocene(?) fanglomerate but underlies the extensive olivine basalt flows and the Pleistocene fanglomerate southwest of Towne Pass. The Pleistocene fanglomerate, in turn, is tilted and truncated by a surface of probably late Pleistocene age. Both tilted fanglomerates are shown as one unit on the economic map (pl. 1).

The Paleozoic rocks were deformed into broad open north- to N. 20° W.-trending folds that were disrupted by numerous faults. In the Panamint Range within the Panamint Butte quadrangle the Paleozoic rocks were only gently deformed during the Mesozoic orogeny. The distribution of rock types in the Panamint Range shown on the Death Valley geologic sheet (Jennings, 1958) with Archean rocks along the crest and in general with younger rocks to the east and west shows that the range is an anticline but is greatly complicated by faulting. The distribution of Paleozoic rocks in the Argus Range also reflects a broad anticline that plunges north (pls. 1, 2).

Two major thrust faults were mapped in the Panamint Range. The Lemoigne thrust in the northeast part of the quadrangle has probable Middle and Upper Cambrian dolomite thrust over thinly bedded limestone of Pennsylvanian and Permian age (pl. 1). The stratigraphic displacement is about 6,000 feet. A large drag fold, which is a conspicuous geologic feature on the west face of the Panamint Range, shows that the thrusting was towards the southeast (photo 6). A second thrust, exposed near the southeast corner of the quadrangle and undoubtedly underlying all the Paleozoic rocks north to Towne Pass, has medium-bedded dolomite of Cambrian(?) and Ordovician age thrust over Precambrian(?) dolomite and quartzite (pl. 1). The direction or magnitude of displacement of this thrust is not known. The age of the thrusts is probably Late Triassic or Early Jurassic. The Lemoigne thrust sheet, which involves strata of Permian age, is intruded, deformed, and contact metamorphosed by quartz monzonite dated as 180 million years old by potassium-argon and lead-alpha methods.

Photo 6. The Lemoigne thrust, on the west face of the Panamint Range 1.4 miles east of the Big Four mine. Dolomite of Cambrian age in the upper left part of the photograph is thrust over overturned thinly bedded limestone of the Keeler Canyon formation of Pennsylvanian and Permian age. Thrusting was toward the southeast (from left to right).

A left-lateral strike-slip fault striking N. 70° W. in the Argus Range about 1,900 feet north of the Surprise mine is a late phase of the Mesozoic orogeny (pl. 1). Displacement on the fault is 2,000 feet, north side moving west relative to the south side.

Both the biotite-hornblende quartz monzonite in the Panamint Range, which is a continuation of the Hunter Mountain quartz monzonite in the Ubehebe Peak quadrangle (McAllister, 1956), and the quartz monzonite in the Argus Range were forcibly intruded into folded Paleozoic rocks (pls. 1, 2). Deformation by the intrusives extends about half a mile from the contacts. The Modoc district map shows particularly well the shouldering aside of the marble and the overturning of beds adjacent to the contact (pl. 2). The axis of the broad anticline north of the intrusion is tightly folded 3,000 feet northeast of the Defense mine and has been displaced more than 1 mile to the east. Adjacent to the intrusion the Tin Mountain limestone and Perdido formation have been deformed into an overturned syncline (pl. 2). Several small thrust faults and steep faults disrupt the marble in the Modoc district near the intrusive.

A broad regional warp broken by three sets of faults formed the present east-tilted mountain ranges and enclosed Panamint basin. Both the Argus and Panamint Ranges are on the east flank of a regional warp, which has an axis along Owens Valley. Late Piocene or early Pleistocene fanglomerate and basalt on the west flank of the Panamint Range are tilted to dips as much as 39° E., and the extensive middle Pleistocene olivine basalt flows in the Argus and Panamint Ranges dip 5° to 15° E. (pl. 1). The warp is broken by right-lateral strike-slip faults striking northwest, left-lateral strike-slip faults striking northeast, and normal faults striking north. The faults are best developed on the west flank of the Panamint Range while the east flanks of both ranges are essentially dipslopes that are broken mainly by small mountain-down faults, for example, the one on the west side of Ash Hill in the Argus Range (pl. 1).

The range-front faults on the west side of the Panamint Range are at least in part right-lateral strike-slip faults. Right-lateral displacement is shown by the displaced drainages in the canyons south of State Highway 190 and by drag in the Tin Mountain limestone at the base of the range east of Lake Hill. Left-lateral strike-slip faults show up strikingly in the northeast-trending canyons east of Lake Hill (pl. 1, photo 7). Maximum displacement on these northeast-striking faults is about 1½ miles. Both the map pattern and abundant nearly horizontal mullions indicate the left-lateral movement (photo 8). Two north-striking normal faults displace the Cenozoic deposits into three steps in the southeast part of the quadrangle. Displacement on the faults is approximately 4,800 feet for the western one and 9,000 feet for the fault southeast of Towne Pass (pl. 1).

Abundant slumps in the Panamint Range formed at the time of warping and faulting during the late Pliocene and Pleistocene. Slumps occurred because of the steep topography and wet climate during the late Cenozoic and because of the large amount of shattering of the Paleozoic bedrock by the Mesozoic thrust faults. In some places the Paleozoic carbonate rocks are shattered to blocks mostly less than 1 foot in maximum dimension for as much as 1,000 feet above a thrust. During the Pleistocene period of wet climate and steep topography, the shattered Paleozoic rocks slid across surfaces that dipped

Photo 7. View of the west face of the Panamint Range showing the left-lateral displacement of the Lee Flat limestone (ℙMlf) and Keeler Canyon formation (PℙKc) by northeast-striking faults in the canyons. The Lemoigne thrust overlain by dolomite of Cambrian age (Ꞓd) is in the upper left.

Photo 8 (below). Nearly horizontal mullions on a northeast-striking left-lateral strike-slip fault in the Panamint Range, 2½ miles east of the north end of Lake Hill.

as low as 8°. Slumping and debris flows account for the abundant monolithologic breccia lenses interbedded in the old fanglomerate east of Towne Pass and in part for the distribution of olivine basalt extending from the top nearly to the foot of the Panamint Range near the Big Four mine (pl. 1). Lake Hill also possibly slid on a low angle gravity fault from an area of similarly shattered Ordovician rocks 3½ miles to the east. Donald Mabey (oral communication) of the Geological Survey found no geophysical evidence for a large steep fault bounding Lake Hill to account for its position in the valley, and an origin by sliding seems most probable. An origin by gravity sliding is evident for a small hill of brecciated limestone of Pensylvanian age that overlies basaltic agglomerate in Panamint Valley 2 miles north of Lake Hill. The Pennsylvanian limestone is 1,600 feet from the range front where similar limestone is exposed under the Lemoigne thrust.

MINERAL DEPOSITS

TYPES OF DEPOSITS

Lead, silver, zinc, copper, and gold are the only commodities that have been exploited in the Panamint Butte quadrangle and adjoining Modoc district. Most of the lead and silver has come from the Modoc district in the Argus Range (pl. 2), but some has come from several small mines in the Panamint Range (pl. 1). The deposits are all in carbonate rocks and in general are small but high grade.

Gold has been produced as the principal commodity from only one mine, but there are other gold mines in Snow Canyon in the Argus Range 2 miles south of the Modoc district in what was formerly known as the Sherman district. Some prospecting was done for uranium in the Argus Range during the early 1950's; several claims were staked, but very little work was done on them.

Nonmetallic commodities include calcareous clay, limestone, and dolomite. The Eureka quartzite is not suitable for super refractory silica brick as it is in the Darwin quadrangle (Hall and MacKevett, 1958, p. 72) or near Owens Valley. Abundant limestone is present in the Argus Range and dolomite in the Panamint Range, but the area is remote from market and rail transportation.

Photo 9. View northeast toward the Modock furnaces on Lookout Mountain. Date of the photograph is not known. Photo furnished by Inyo County Museum, Independence.

Calcareous clay crops out in the southwestern part of the playa in Panamint Valley (pl. 1). Numerous pits have been dug in exploration of the clay.

HISTORY AND PRODUCTION

High-grade lead-silver ore was first discovered in the Modoc district in 1875 according to Tucker and Sampson (1938, p. 445), during a period of intense activity at the nearby Darwin, Cerro Gordo, and Panamint districts. Mining in the district between 1875 and 1890 was mainly at the Modoc mine (Modock mine) by the Modock Consolidated Mining Co. The Modoc mine, according to Crawford (1894, p. 24), produced $1,900,000 in silver, gold, and lead between 1875 and 1890. Two 30-ton smelters were built by 1884 to treat the ore (Burchard, 1885, p. 104) (photo 9). Charcoal for the furnaces was obtained from charcoal kilns in Wildrose Canyon. During this period, the town of Lookout on the top of Lookout Mountain in the Modoc district (pl. 2) was a thriving community. Now all that remains of the town are some stone foundations. Activity at the Modoc mine started to wane by the late 1880's, and little ore has been produced since 1897 except for reworking dumps and slag piles.

No record was found of production from the Minnietta mine prior to 1890, although Raymond (1877) mentions work being done at the Minnietta (Mineatta) during 1876 and DeGroot (1890, p. 210) lists it as one of the mines of the district as of 1889. Later the mine is described as the St. John and St. Arthur mines by Crawford (1894, p. 24). The principal production from the Minnietta mine was between 1895 and 1905 by J. J. Gunn and between 1915 and 1920. Since 1948 the mine has had a small production from lessees.

The Defense mine was located originally during the early period of activity in the district, but little work was done until much later. The earliest known production was during the 1930's, but most of it has been since 1948. The Surprise mine apparently was not located until 1941, and nearly all its production was between 1947 and 1951.

The lead-silver mines in the Panamint Range are small and the value of the recorded production is about $70,000. The Big Four mine on the west side of the Panamint Range was originally located in 1907, but the only recorded production was between 1944 and 1952. The Lemoigne mine on the east side of the Panamint Range was first worked in 1918, but the first mention of it in the literature is by Tucker (1926, p. 488). Most of the production from the mine was in 1925 and 1927.

Table 2. Production of gold, silver, copper, lead, and zinc from the Panamint Butte quadrangle and Modoc district.

Year	Gold (ounces)	Silver (ounces)	Lead (pounds)	Copper (pounds)	Zinc (pounds)
1875 to 1890*					
1891...	196.98	65,016			
1892...	29.02	21,420			
1893...	32.41	24,872			
1895...	27.57	49,727			
1897...	241.87	25,850			
1898...	174.15	33,559			
1899...	48.37	20,000			
1900...	241.87	29,569			
1901...	96.75	18,333			
1902...	96.76	20,000			
1903...	48.37	25,926	119,048		
1904...	24.19	31,034	10,000		
1905...	241.87	29,508	100,000		
1910...	4.98	2,285	520	7,968	
1915...	..	1,006	16,403		
1916...	110.00	19,061	101,377	1,866	
1917...	..	9,489	84,000		
1918...	2.00	4,454	42,046		
1919...	3.00	686			
1920...	22.00	9,046	16,605	120	
1925...	6.55	875	147,986	37	
1927...	113.76	397	20,500	300	
1930's..	(year unknown)	unknown	76,500		
1930...	21.55	5			
1931...	78.30	9			
1932...	70.80	9			
1933...	7.08	1			
1934...	30.31	11			
1935...	6.06	3			
1937...	2.00	1			
1941...	154	169	12,094	103	
1942...	42	472	56,302		
1943...	..	639	24,502	352	
1944...	9	2,774	67,082	1,782	21,158
1945...	35.00	42,966	1,723,800	95,635	
1946...	59	19,960	573,177	27,972	
1947...	51	14,001	455,381	4,353	730
1948...	61	60,675	23,296	9,982	3,257
1949...	42	41,171	1,493,883	7,080	
1950...	20	11,941	178,097	1,469	49,476
1951...	29	29,935	650,086	10,641	8,537
1952...	10	9,528	265,414	3,545	42,035
1953...	19	28,918	384,218	5,797	45,811
1954...	31	43,675	726,743	3,843	38,597
1955...	28	39,261	640,363	5,292	28,450
1956...	24	32,168	783,272	2,631	16,536
1957...	24	28,445	777,181	633	1,901
Totals	2,617	848,850	9,569,876	191,401	256,488

* Value of production from the Modoc mine is $1,900,000 Crawford, 1894, p. 24); the production of the Minnietta mine is unknown although early activity reports show that it was worked part of this period.

The total value of lead, silver, zinc, copper, and gold from the Panamint Butte quadrangle and Modoc district is about $3,900,000. Lead and silver from the Modoc district make up the largest share and together total $3,740,000. Prior to 1903 production records were kept only of silver and gold and undoubtedly a considerable amount of lead was recovered as lead bullion. Similarly the production records do not show zinc recovered until 1944. Probably the zinc was lost in the slag in the early smelting of the ore. Gold was recovered both from the lead-silver ore and from gold-quartz veins mined at the Little Mack mine. The total value of the recorded production of gold is $63,000, of which $8,400 is from the Little Mack mine and the rest from lead-silver ore.

A summary of the total recorded production from the Panamint Butte quadrangle and the Modoc district is given in table 2.

LEAD-SILVER DEPOSITS

Distribution

Lead-silver deposits are concentrated in the Modoc district in the northern part of the Argus Range between Thompson and Osborne Canyons (pls. 1, 2). The principal mines are the Defense, Minnietta, Modoc, and Surprise. A number of prospects are present in the Argus Range north and northwest of the Modoc district to Zinc Hill in the Darwin quadrangle, but the mineralization in general is scanty.

Several small lead-silver deposits are in the Panamint Range widely spaced from each other (pl. 1). Two mines—the Big Four and the Lemoigne—have had a known production. The Kerdell prospect has had considerable exploration work but no known production.

Size and character of ore bodies

The lead-silver ore bodies in both the Modoc district and the Panamint Range are small and high grade. Argentiferous galena is the principal primary ore mineral, and chalcopyrite, pyrite, and sphalerite are present in small quantities. Some of the small primary ore bodies consist predominantly of galena, for example, the high-grade ore body north of the Foreman ore body in the Defense mine (see pl. 3). Most of the ore bodies are at least in part altered to supergene minerals, and some are completely altered. Cerussite, mimetite, and pyromorphite are the common secondary lead minerals in the secondary ore that lacks manganese. At the Defense, Minnietta, and Modoc mines secondary manganese minerals are abundant in the near-surface ore bodies, and the ore is a dark-brown or black fine-grained mixture of cerussite, coronadite, cryptomelane, relict galena, jasper, and pyrolusite.

Most ore bodies are flat-lying pod-shaped masses that have sharp contacts with the carbonate host rock. The two largest ore bodies in the Defense mine, the upper ore body and the Foreman ore body, contained about 12,000 tons of ore that averaged about 20 percent lead and 17.5 ounces per ton in silver. Both ore bodies which are now mostly mined out are about 240 feet long. The upper ore body is 10 to 30 feet wide and 2 to 14 feet thick and the Foreman ore body is 10 to 70 feet wide and 2 to 14 feet thick (see pls. 3, 4). The largest ore body in the Minnietta mine in the Jack Gunn workings is about comparable in size (pl. 6).

Little is known about the size or grade of ore in the Modoc mine, as it has not been operated for many years and most of the workings are inaccessible because of fill. However, the No. 4 ore body probably is the largest in the district (sec. B-B', pl. 7). The ore is along a fault that strikes N. 50° E. and dips 55° to 70° SE. Locally ore has extended along flat fractures to make tabular bodies away from the main fault. On the No. 4 level this ore body occurs along a flat structure and has been stoped for a strike length of 170 feet and a maximum width of 60 feet. The ore body has been stoped discontinuously from the surface to the No. 3 level, a vertical distance of about 180 feet. Undoubtedly several tens of thousands of tons of ore was mined from it. Most other ore bodies in the district and those in the lead-silver mines in the Panamint Range are much smaller. Some pods in the Surprise mine contained only a few tons of ore and ore bodies of a few hundred tons in the Modoc district are common.

The ore bodies characteristically have sharp contacts with only slightly mineralized or unmineralized carbonate host rock—usually marble. The ore is in large part oxidized, especially where it is in or near steep faults that served as channelways for downward percolating groundwater. Flat-lying ore bodies that are not broken by steep faults like the Foreman ore body in the Defense mine are largely primary galena ore.

Some silver ore is present at the margin of the Foreman ore body in the Defense mine (see pl. 3). The silver ore contains very little galena. It appears as a yellowish and greenish stain in a porous gangue of calcite and chalcedony. Silver is present in the form of cubes and irregular smears of cerargyrite in the oxidized ore. The silver ore apparently is a lower temperature peripheral zone to a high-grade galena ore body. A small amount of similar oxidized silver ore is present at the north end of the principal flat-lying stope in the Lemoigne mine (pl. 12), and in the upper end of the Jack Gunn stope in the Minnietta mine (pl. 6).

Ore controls

The lead-silver deposits are localized in carbonate rocks of Paleozoic age near contacts with quartz monzonite or within an intrusive near its margin (pls. 1, 2). No lead-silver mine in the area with a recorded production is more than 1½ miles from a quartz monzonite pluton. The two types of quartz monzonite present—biotite-hornblende-quartz monzonite and leucocratic quartz monzonite—are equally favorable; deposits are near both intrusive types.

In addition to being localized near an intrusive, the lead-silver deposits have a stratigraphic or structural control or both. Pure limestone recrystallized to marble is the most favorable host rock in the Argus Range from the Modoc district northwest to Zinc Hill in the Darwin quadrangle. The Lost Burro formation of Devonian age, Tin Mountain limestone of Mississippian age, and the Lee Flat limestone of Mississippian and Pennsylvanian(?) age —all relatively pure limestones that recrystallized readily to marble—contain ore deposits. The Modoc and Minnietta mines are in the Lost Burro formation and the Surprise and Defense mines are in the Tin Mountain limestone. It is apparent from the sporadic mineralization in relatively pure marble and not in silty limestone in the area northwest of the Modoc district that pure marble is favorable and that silty limestone of Pennsylvanian and Permian age is unfavorable. However, in the Panamint Range ore at the Lemoigne mine is in diagenetic dolomite, which in the Darwin quadrangle (Hall and MacKevett, 1958, p. 16) and in the Modoc district is an unfavorable rock type.

A structural control is in part responsible for the localization of all the lead-silver deposits. Most of the ore bodies are localized in flat sheeted zones, cutting across bedding, that are localized close to major steep N. 70° W.-striking faults. The sheeting most likely represents tension fractures adjacent to the steep N. 70° W. shears. The following examples illustrate a control by flat faults or fractures. At the Minnietta and Modoc mines in the Modoc district and the Big Four mine in the Panamint Range thrust faults are important ore controls. At the Minnietta mine, the Jack Gunn thrust is discontinuously mineralized for a distance of 1,350 feet (pl. 5). At the Modoc mine a number of small ore bodies have been mined in the footwall of a thrust fault that has been mineralized over a strike length of 600 feet (pl. 7), and at the Big Four mine ore is in or near a major thrust fault that has Ordovician(?) dolomite over limestone and marble of Pennsylvanian and Permian age. At the Defense mine the ore is in flat zones that cut across bedding. No strong or continuous fault is evident, and the ore seems to be controlled by flat fractures or sheeted zones. At the Lemoigne mine the principal ore body is parallel to bedding.

The only mine in the area that does not have a flat structural control is the Surprise. Ore in the Surprise mine is localized near the crest of an anticlinal fold in or near the intersection with a steep fault striking about N. 50° E. (pl. 9).

Mineralogy

The minerals identified in the lead-silver deposits in the Panamint Butte quadrangle and Modoc district are listed on page 26.

Hypogene minerals

The primary ore in the lead-silver deposits consists of medium- to coarse-grained galena and small amounts of pyrite, sphalerite, and chalcopyrite in a gangue predominantly of chalcedony, jasper, and calcite. In addition specularite is an abundant mineral at the Big Four mine. Galena is by far the predominant ore mineral at most mines; some faces in the Defense mine on the intermediate level, for example, consisted almost entirely of it. Sphalerite, chalcopyrite, and pyrite are sparsely disseminated in most ore bodies. Sphalerite was abundant originally only at the Big Four mine, where the ore contains about equal amounts of lead and zinc. The presence of abundant specularite and jasper at the margin of the main

HYPOGENE MINERALS	
Metollic minerols	
Cholcopyrite	$CuFeS_2$
Goleno	PbS
Pyrite	FeS_2
Speculorite	Fe_2O_3
Spholerite	ZnS
Gongue minerols	
Colcite	$CoCO_3$
Cholcedony	SiO_2
Josper	SiO_2
SUPERGENE MINERALS	
Sulfide zone	
Covellite	Cu_2S
Oxide zone	
Bindheimite	$Pb_2Sb_2O_6(O,OH)$
Coledonite	$Cu_2Pb_5(SO_4)_3(CO_3)(OH)_6$
Cerorgyrite	$AgCl$
Cerussite	$PbCO_3$
Coronodite	$MnPbMn_6O_{14}$
Cryptomelone	KMn_8O_{16}
Gypsum	$CoSO_4.2H_2O$
Hemimorphite	$H_2Zn_2SiO_5$
Hydrozincite	$2ZnCO_3.3Zn(OH)_2$
Jorosite	$KFe_6(OH)_{12}(SO_4)_4$
Limonite	Hydrous iron oxide
Linorite	$(Pb,Cu)SO_4.(Pb,Cu)(OH)_2$
Mimetite	$Pb_5(AsO_4,PO_4)_3Cl$
Pyromorphite	$Pb_5(PO_4,AsO_4)_3Cl$
Pyrolusite	MNO_2
Wulfenite	$PbMoO_4$

ore body of the Big Four mine makes the mineralogy of this mine unique for this area.

Supergene minerals

Most ore bodies are altered to supergene minerals to some extent, and many are nearly completely altered. The supergene ore consists predominantly of bindheimite, cerussite, coronadite, cryptomelane, hemimorphite, mimetite, pyrolusite, and wulfenite in a gangue of calcite, gypsum, jarosite, jasper, and limonite. A little relict galena remains in most supergene ore. Cerargyrite and the oxidized copper minerals linarite and caledonite are present locally in small amounts. Cerussite is the principal secondary lead mineral formed from the oxidation of galena ore bodies, but it is not abundant in the oxide ore that contains large amounts of manganese. Bindheimite is present in small amounts in most oxide ore containing cerussite and relict galena. It forms a yellow powdery coating on the cerussite.

An unequivocal primary source has not been found for either the arsenic or the abundant manganese in the Modoc district supergene ores. Coronadite, cryptomelane, pyrolusite, and relict galena in a jasper gangue made up most of the upper ore body at the Defense mine, which was mined during the late 1940's. Samples of this ore body contained 18 to 27 percent manganese (Norman and Stewart, 1951, p. 69). Black sooty manganese oxide stains much of the rock and is abundant in fault zones at both the Modoc and Minnietta mines, and it is probable coronadite also was a common ore mineral in the near-surface ore bodies mined many years ago from these mines.

Cerargyrite is present in the oxidized silver ore that is peripheral to the Foreman ore body on the intermediate level of the Defense mine and at the upper margin of the Jack Gunn stope in the Minnietta mine. It is an olive-green soft mineral with a waxy luster that forms tiny cubes and thin smears associated with yellow powdery bindheimite, linarite, and caledonite in a gangue of chalcedony and calcite.

Coronadite was identified by X-ray diffraction pattern and by X-ray spectrographic analysis. It is a dense massive, dark-gray mineral with a conchoidal fracture. The X-ray spectrographic pattern indicated manganese and lead as major constitutents and some zinc and iron. The X-ray diffraction pattern was similar to that given by Frondel and Heinrich (1942, p. 51) and by Fleischer and Richmond (1943, p. 280), who had previously identified coronadite from the Modoc district.

Coronadite from the Defense mine		Coronadite from Coronado vein, Arizona (from Fleischer and Richmond, 1943, p. 280)			
dÅ	Intensity	dÅ	Intensity	dÅ	Intensity
3.466	6	3.487	9	1.63	7
3.104	10	3.327	1	1.53	8
2.400	4	3.113	10	1.42	1
2.205	4	2.387	7	1.39	3
2.156	2	2.198	8	1.37	3
1.84	2	2.159	6	1.36	6
1.74	1	1.940	3	1.30	2
1.69	1	1.83	7	1.24	3
1.64	2	1.74	2	1.22	3
1.54	5	1.68	3	1.20	2
1.43	1			1.18	4
1.40	1				
1.39	2				
1.36	2				
1.30	1				
1.24	1				
1.22	1				

Cryptomelane occurs with coronadite and pyrolusite in a jasper gangue in the upper workings of the Defense mine. It is in dense, fine-grained dark-gray masses that have a conchoidal fracture. The identification is based on similarity to an X-ray diffraction pattern given by Fleischer and Richmond (1943, p. 280).

Mimetite is a moderately abundant supergene mineral at both the Surprise and Defense mines. The mimetite forms yellowish-green botryoidal or fine-grained porous masses on cerussite and relict galena.

Pyrolusite is associated with the coronadite and also occurs as a black sooty coating along faults near ore bodies. Some of the pyrolusite with coronadite forms radial growths of delicate acicular crystals, but most of it forms dense, fine-grained masses or black sooty coatings.

Wulfenite is not abundant, but was found at the Lemoigne mine (pl. 12) at the north end of the main ore body as bright yellow tabular crystals on fractures.

Gangue minerals are generally not abundant except in the siliceous silver ore at the margin of the Foreman ore body at the Defense mine (pl. 3) and in the manganese-rich ore bodies. The primary gangue minerals are mainly calcite and chalcedony. Reddish-brown jasper, which is a very abundant gangue mineral in the manganese-bearing oxidized ore, formed from abundant veining and filling of vugs in chalcedony by limonite—producing a dense, reddish-brown rock. The jasper forms irregular masses in coronadite; it is disseminated in small patches in fault zones at the surface near ore bodies, and it forms large masses under the north end of the Foreman ore body. Jarosite, gypsum, and limonite are other common supergene gangue minerals.

Wall-rock alteration

Except at the Modoc and Minnietta mines, there is no distinct alteration adjacent to the lead-silver ore bodies. At both these mines the white marble or light-gray limestone host rock is altered yellowish on fresh surfaces and weathers to light brown. The alteration is in part dolomitization of the limestone or marble country rock and in part is disseminated limonite in marble. The altered rock commonly must be tested with dilute hydrochloric acid to differentiate the brown-stained marble from brownish dolomitized marble. Dolomitization is common along faults close to ore bodies. The brown-stained alteration commonly pervades the marble near thrust faults as at the Modoc mine (pl. 7). Black manganese oxides accompany the brown-stained marble and dolomitized marble along the Jack Gunn thrust at the Minnietta mine and in faults near ore at the Modoc mine. Black manganese oxides are also present along faults near the upper ore body of the Defense mine. The distribution of the black staining near ore bodies suggests that the original manganese was introduced by hydrothermal solutions at the time of ore deposition.

Mines and prospects in the Modoc district

Defense mine

The Defense mine is in the central part of the Modoc district in the northwest part of the Maturango Peak quadrangle (pl. 2). It is at the head of the unnamed canyon north of Stone Canyon at altitudes of 4,000 to 4,500 feet. Topography in the area is steep, averaging 42° on the slope north from the mine workings. The mine is accessible by a steep gravel road that connects with the hard-surfaced road to Trona in Panamint Valley and to a gravel road that intersects State Highway 190, 1¾ miles east of Panamint Springs (fig. 1). The latter road was washed out in July 1958.

The property consists of five unpatented claims owned by L. D. Foreman, Mary R. Foreman, and Ida L. Cannon and is operated by Robert Foreman of Lone Pine, California. The mine is developed by a series of interconnected adits, crosscuts, and winzes on three levels at altitudes of approximately 4,273, 4,240, and 4,146 feet and by several large flat-lying stopes (pl. 3).

The Defense mine was originally located in the 1870's during the main period of development of the Modoc district, but no production was made at that time. The mine was relocated during the 1930's by C. C. King and J. C. Hodges, who produced 225 tons of ore that averaged 17 to 18 percent lead according to Norman and Stewart (1951, p. 68). L. D. Foreman and W. V. Skinner purchased the mine in 1947, and the present owners obtained control in 1951.

The nearest water supply is at Jack Gunn spring about 2 miles distant over a steep gravel road that is best negotiated with a four-wheel drive vehicle. The spring normally flows about 900 gallons per day according to mine owners. The water is piped 3,000 feet down Stone Canyon to a water tank near the Defense mine road, and the water is hauled about 3,500 feet by truck to the mine.

Field work. The field work upon which this mine description is based was started in July 1953 by E. M. MacKevett, Jr., and W. E. Hall at the request of the Defense Minerals Exploration Administration regarding an application from the owners for financial assistance in exploration. Diamond drilling under terms of a DMEA contract resulted in the discovery of the Foreman ore body. Later the writers periodically visited the mine while mapping the Panamint Butte quadrangle and mapped the mine workings in April 1957 and October 1958.

Production. The recorded production from the Defense mine has a gross value of about $1,300,000 through 1957. The 13,337 tons of ore mined from 1942 through 1955 averaged about 20 percent lead and 17 ounces silver per ton. The ore is trucked without concentration to Trona and by rail to the Selby smelter. A summary of the production is given in table 3.

Geology. The mine area is underlain by thinly bedded limestone, cherty limestone, and marble of Mississippian age that are part of the Tin Mountain limestone, Perdido formation, and Lee Flat limestone (pl. 4). The

Table 3. Production from the Defense mine.

(Compiled from files of the U. S. Bureau of Mines and published with permission of the mine owners.)

Year	Dry tons	Gold ounces	Silver ounces	Copper pounds	Lead pounds	Zinc pounds
1938..	225	..	..	..	75,000*	
1942..	135	1	410	457	50,452	
1943..	44	..	639	352	24,502	
1947..	462	1	3,974	870	209,901	
1948..	4,086	32	49,027	8,202	1,728,755	
1949..	2,543	26	32,276	5,732	1,003,700	
1950..	199	1	2,939	428	59,288	786
1951..	1,229	13	18,110	8,831	409,016	8,537
1952..	474	7	6,289	2,214	143,670	9,962
1953..	1,146	19	28,615	5,561	384,218	45,811
1954..	1,654	31	43,480	3,744	715,873	37,897
1955..	1,325	28	39,261	5,292	604,363	28,450
1955..	40	1	245	80	5,711	402
1956..	974	24	32,168	2,631	783,272	16,536
1957..	1,140	23	26,824	429	728,606	840
Total...	15,676	207	284,257	44,823	6,926,327	149,221

* Approximate figure from Norman and Stewart, 1951, p. 78.

Tin Mountain limestone crops out in the northern part of the mine area and is the host rock for all the known ore bodies. It consists of thinly bedded bluish-gray limestone that is in part recrystallized to white marble. Poorly preserved syringoporoid corals were found in the limestone between faults A and B (pl. 4). The Perdido formation is 165 feet thick and consists of thinly bedded bluish-gray limestone containing lenses of chert several feet long and 1 to 3 inches thick. Locally, chert is sufficiently abundant to constitute about a fourth of the rock. The Perdido is in large part altered to a conspicuous brown calc-silicate rock or to white marble with small irregular masses of calc-silicate minerals. The calc-silicate rock consists mainly of coarse-grained garnet, idocrase, and wollastonite. The Lee Flat limestone, which crops out in the southern part of the mine area, consists of white, medium to thickly bedded marble.

The Paleozoic rocks are intruded by several small bodies of granodiorite that are offshoots of a pluton of biotite-hornblende quartz monzonite that underlies Maturango Peak and by a dike of altered greenish-gray andesite porphyry (pl. 4).

Structure. The Paleozoic rocks strike N. 50° to 80° W. and dip mainly steeply northeast in an overturned section that comprises the Tin Mountain limestone of Early Mississippian age in the northern part through the Perdido formation to Lee Flat limestone of Mississippian and Pennsylvanian(?) age in the southern part (pl. 4). The Perdido formation was an incompetent unit and formed what is interpreted as a tight anticline and syncline, based on the distribution of cherty limestone, although the actual folding over of the beds is not evident. However, it is common for the crests of tight folds in this area to be inconspicuous because of faulting and brecciation.

The Paleozoic rocks are cut by a series of northwest-striking faults which have conspicuous brecciated zones mostly 2 to 3 feet thick but locally as much as 20 feet thick. The brecciated zones contain comminuted Paleozoic rocks, lenticular masses of jasper, and secondary manganese, lead, and iron minerals. As there are no marker beds in the mine area, the direction and amount of displacement is not known. The only slickensides are steeply plunging ones on fault A. A reverse movement is indicated by the steeply plunging slickensides and by the flat tension fractures.

Underground a flat structure that controls ore distribution is evident between faults A and B; this structure does not crop out at the surface (pl. 3). In general it is a flat sheeting, but locally movement is evident.

Ore deposits. Small high-grade ore bodies are present along flat-faulted or sheeted zones that cut across bedding of the Tin Mountain limestone between faults A and B (pl. 4). Most of the ore has come from two ore bodies. The upper ore body mined from the 106 stope (sec. A-A′, pl. 4) is a flat ore body 240 feet long, 10 to 30 feet wide, and 2 to 14 feet thick. The Foreman ore body on the intermediate level is 240 feet long, 10 to 70 feet wide, and 2 to 14 feet thick (pl. 3). All other ore bodies are much smaller.

The ore bodies are in a series of four steps in flat-fractured zones that decrease in altitude toward the northeast (pl. 4). Two of the steps are above the upper adit in the glory-hole workings (pl. 4). A third step is in the upper stope and the fourth on the intermediate level. In the upper ore body in the 106 stope, the ore is localized on the northeast side of a bedding plane fault, which strikes N. 40° W. and dips 56° NE., by a fractured zone that strikes north to northwest and dips 10° E. The flat-lying fracturing on the intermediate level is 35 feet lower and 65 feet north of that in the 106 stope. Some galena was encountered in diamond drill hole 11A between the two levels, which suggests that the flat structures are interconnected by a steeper, probably bedding-plane fracture (pl. 4). The fractures on the intermediate level strike eastward and dip a few degrees south. The backs and floors of the Foreman and intermediate stope ore bodies on the intermediate level are controlled by flat fractures except at the north end of the Foreman ore body where the flat fracturing dies out and the ore body is controlled by bedding. Some manganese and iron minerals are disseminated in the limestone northwest of the Foreman ore body. A small high-grade ore body is present 40 feet N. 20° W. of the northwest end of the Foreman ore body. The ore body plunges 25° N. 20° W. It is 70 feet long, a maximum of 20 feet wide, and 12 feet high.

Both primary and secondary ore has been mined from the property. The ore mined from the upper ore body and the glory hole was mainly secondary ore consisting of cerussinte, coronadite, cryptomelane, pyrolusite, relict galena, and a little pyrite and mimetite in an iron- and manganese-stained calcite and jasper gangue.

The ore mined since 1953 from the intermediate level is both primary and secondary. The ore in the Foreman ore body consisted of galena in crudely spherical relict masses surrounded by cerussite and lesser pyrolusite, bindheimite, and some blue and green copper minerals. Gangue minerals were jasper, calcite, limonite, and gypsum. The ore from the high-grade stope, 40 feet north of the Foreman ore body, was entirely primary ore and consisted of galena and a little calcite gangue.

Low-grade silver ore occurs peripherally to galena ore in the Foreman ore body (pl. 3). The silver ore is in the same flat ore-controlling fractures as the lead-silver ore. Few sulfide minerals are in the silver ore although an occasional galena crystal can be found. The ore consists of a little yellow bindheimite, linarite, caledonite, and brochantite along fractures in a partly silicified limestone. Tiny crystals or masses of soft, waxy olive-green cerargyrite are disseminated in the caledonite or yellow bindheimite. The cerargyrite is very inconspicuous as it is commonly coated with limonite or jarosite. One carload shipment of silver ore from the north end of the Foreman ore body contained 98 ounces of silver per ton. Most of the silver ore, though, is lower grade.

Lead mine (Hughes group)

The Lead mine is in the Maturango Peak quadrangle in the Modoc district on the south side of Stone Canyon 2,500 feet northwest of the Modoc mine at an altitude of 3,040 feet (pl. 2). Four claims are owned by Mason E. Franklin of Los Angeles, California. A short gravel road leads to the mine from the road to the Defense mine in Stone Canyon.

The property has been idle for many years and the shaft was boarded over so the workings were inaccessible. Norman and Stewart (1951, p. 73) describe the property briefly, and the following description is from them.

> "Lead minerals, carrying silver and gold, are in replacement bodies in limestone. The property has a 160-foot nearly-vertical shaft from which drifts have been driven on three levels. Level workings total approximately 200 feet.
>
> "According to the owner, no ore has been produced since 1926 when ore valued at $45,000 was shipped. The property was leased by R. E. Major from the fall of 1946 to the spring of 1947; the shaft was deepened 60 feet and drifts were driven on the 100 and 160-foot levels. Some lenses of ore were found which assayed as high as 60 percent lead, 19 ounces of silver and from ½ to 2 ounces of gold per ton (oral communication from Mr. Major)."

The host rock in the mine area is the Lost Burro formation of Devonian age. It consists of thin- to medium-bedded, light-gray marble that is locally iron-stained and dolomitized. The bedding strikes N. 40° W. and the predominant dip is steep to the NE, but locally the beds are overturned in the vicinity of the mine workings and dip SW. According to R. E. Major (written communication, 1959) an ore body was mined along the inclined shaft from the surface to a depth of 100 feet along a fault that strikes N. 78° W. and dips 60° NE. On the 40-foot level the ore body had a cross sectional area of 10 by 12 feet and at the bottom of the ore shoot it was 12 by 15 feet.

Little Jim prospect

The Little Jim prospect is located in the Modoc district in the Argus Range in sec. 25, R. 41 E., T. 19 S., 1.6 miles N. 83° W. of the Defense mine (pl. 2). The claim is accessible by a steep gravel road in Stone Canyon. According to claim notices the prospect was located July 25, 1947, by W. V. Skinner.

The prospect is underlain by white coarsely crystalline thickly bedded marble of the Lee Flat limestone. Bedding in the marble strikes N. 80° E. and dips 80° S. Thinly bedded limestone of the Keeler Canyon formation conformably overlies the marble 400 feet north of the prospect. Diorite crops out about 700 feet north of the prospect.

Four open cuts expose two mineralized zones in the white marble. One vertical shear zone striking N. 38° E. is iron-stained for 50 feet. A second steep shear zone 150 feet distant strikes N. 75° W. and contains disseminated limonite for 40 feet. No production is known from the prospect.

Minnietta mine

The Minnietta mine is in the Modoc district in the northwest part of the Maturango Peak quadrangle at an altitude of approximately 3,000 feet. The mine is on the north side of Thompson Canyon, immediately south of the Modoc mine. Five miles of gravel road connect the mine with the hard-surfaced Trona highway in Panamint Valley (fig. 1).

The property consists of six claims owned by Mrs. Helen Gunn Edwards of Truckee, California, and it is leased to Clarence R. King of Midway City, California. The mine is developed by three sets of workings totalling approximately 5,000 feet of drifts and adits and 23,000 square feet of stopes. The three sets of workings include the St. Charles or West workings, the Jack Gunn workings, and the Cowshed workings (fig. 2).

Most of the production has come from the Jack Gunn workings.

The mine was probably first located during the 1870's, although the first known production was by F. Fitzgerald

Table 4. Production from the Minnietta mine.

(Compiled from files of the U. S. Bureau of Mines and published with permission of the mine owners.)

Date	Ore prod. (dry tons)	Gold (ounces)	Silver (ounces)	Copper (lbs.)	Lead (lbs.)	Zinc (lbs.)
1895..	..	27.57	49,727			
1897..	..	241.87	15,833			
1898..	..	174.15	33,559			
1899..	..	48.37	20,000			
1900..	..	241.87	29,569			
1901..	..	96.75	18,333			
1902..	150	96.76	20,000			
1903..	200	48.37	25,926	..	119,048	
1904..	200	24.19	31,034	..	10,000	
1905..	200	241.87	29,508	..	100,000	
1910..	20	4.98	2,284	7,968	520	
1915..	14	..	1,006	..	16,403	
1916..	475	110.00	19,061	1,866	101,377	
1917..	121	..	9,489	..	84,000	
1918..	42	2.00	4,454	..	42,046	
1919..	1	3.00	686	..	..	
1920..	567	22.00	9,046	120	16,605	
1944..	..	8.00	2,601	1,738	52,977	
1948..	1,020					
	500	5.00	5,086	1,286	263,431	3,257
1949..	861	5.00	4,483	405	382,386	
1950..	800					
		3.00	2,827	162	44,247	9,472
1950..	140	10.00	4,221	755	33,071	39,218
1951..	1,062	1.00	5,598	1,523	165,598	
	38	7.00	3,884	287	27,356	
1952..	347	1.00	2,839	1,087	84,292	
1953..	56	..	196	224	12,952	224
1954..	49	tr.	195	99	10,870	700
1955..	No production recorded					
Totals..	6,863	1,423.75	351,445	17,520	1,567,179	52,871

Figure 2. Composite map of the underground workings of the Minnietta mine, Inyo County.

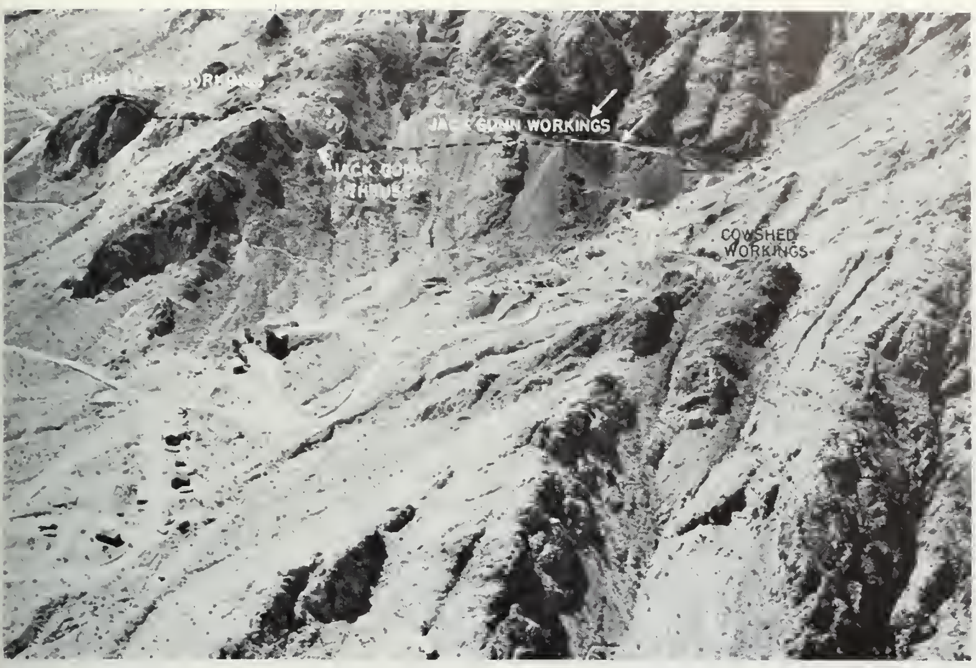

Photo 10. Aerial view of the Minnietta mine area. Camera faces west toward the Jack Gunn thrust. Arrows point to the Jack Gunn vein in the hanging wall of the thrust. Prominent northwest-trending andesite porphyry dikes are in the right center of the photograph.

in 1895. The first mention of the mine in the literature was by Raymond (1877), who mentions activity at the Minnietta mine in 1876. DeGroot (1890, p. 210) listed activity at the mine in 1889 and Crawford (1894, p. 24) described the property at the St. John and St. Arthur mines. The principal period of production was by J. J. Gunn between 1897 and 1915, and by Grimes and Sexton of Trona, California, between 1916 and 1920. There was no recorded production between 1920 and 1944. Since 1944 the property has been worked intermittently by lessees.

Production. The value of the recorded production from the Minnietta mine is approximately $600,000. The production has totalled about 350,000 ounces of silver, 1,400 ounces of gold, 1,500,000 pounds of lead, and a little copper and zinc. A summary of the production is given in table 4.

Geology. The Minnietta mine area is underlain by bluish-gray to white, thin- to medium-bedded limestone and marble that is part of the Lost Burro formation of Devonian age (pl. 5). The limestone is bleached white and recrystallized to marble near flatly dipping faults and commonly is stained by iron and manganese oxides. Locally the marble is dolomitized. The dolomitic parts are light brown and have a sugary texture on weathered surfaces.

The Lost Burro formation is intruded by a series of altered andesite porphyry dikes that strike N. 60° to 70° W. The dikes are part of a dike swarm in the northern part of the Argus Range (pl. 1).

The mine area is on the east limb of a major anticline (pl. 2). Bedding in general strikes northward and dips steeply predominantly to the east. The Paleozoic rocks are cut by a thrust fault that strikes northeast and dips flatly northwest and by steep faults that strike about N. 65° W. The major fault is the Jack Gunn thrust (photo 10). It is exposed for 1,400 feet northeast from the St. Charles workings to a steep N. 65° W. striking fault where it is cut off. The thrust dips approximately 30° NW. Many small flat-lying faults and fractures are in the hanging wall of the Jack Gunn thrust and some are mineralized. Some of the faults that strike N. 65° W. are intruded by andesite porphyry dikes and locally are mineralized (pl. 5).

Ore deposits. The ore bodies in the Minnietta mine are in flat tabular bodies localized close to the Jack Gunn thrust or are in small irregular bodies along steep N. 65° W. faults on andesite porphyry dikes. Most of the ore has come from the Jack Gunn workings, principally from the Jack Gunn stope (pl. 6). The stope is 260 feet long, a maximum of 80 feet wide, and has an average height of 8 feet .The tabular body is localized by flatly dipping fractures in the hanging wall of the Jack Gunn thrust. The ore body strikes N. 40° to 45° W. and dips 20° to 25° NE. Most of the ore has been mined except for some silver ore near the west or upper end of the stope.

The Jack Gunn thrust is mineralized along most of its trace at the surface, containing considerable iron and manganese oxides. Considerable exploration work has been done along the fault in the St. Charles area in highly iron- and manganese-stained marble, but only small amounts of ore were found here.

Ore in the Cowshed workings is along or near faults that strike N. 65° W. and dip steeply southwest (pl. 6). The ore bodies are irregular and extend horizontally apparently along small fractures into the footwall and hanging wall of the steep faults commonly for 30 to 40 feet.

Although only small amounts of ore are visible at the margins of stopes, samples of ore collected during mining operations by Tom Vignich indicate that the ore was principally galena and cerussite in a calcite gangue heavily impregnated with cryptomelane and pyrolusite. The concentration of the manganese minerals is particularly high near the collar of the Merritt incline (pl. 5). Some high-grade siliceous silver ore that contains little lead is present at the west end of the Jack Gunn stope. The silver ore is in a white to light-gray siliceous gangue that contains encrustations and stains of blue and green copper minerals. Abundant minute cubes of cerargyrite and clear prismatic crystals of cerussite are associated with the copper-stained siliceous rock.

Tucker and Sampson (1938, p. 445) describe the ore bodies near the andesite porphyry dikes as being 5 to 20 feet wide, consisting of argentiferous galena, silver chloride and chlorobromides, and containing 30 to 50 percent lead, a quarter ounce of gold, and 50 to 200 ounces of silver per ton.

Modoc mine

The Modoc mine is in the northwest part of the Maturango Peak quadrangle on Lookout Mountain in the N½ sec. 33 (proj.), R. 42 E., T. 19 S., half a mile north of the Minnietta mine and 6.8 miles S. 17° E. of Panamint Springs at altitudes of 3,200 to 3,750 feet (pl. 2). Relief in the area is moderate to steep. The mine is owned by the Modock Consolidated Mining Company of San Francisco, California, which is part of the William Randolph Hearst estate. Mr. J. W. Swent of 100 Bush Street, San Francisco, is responsible for the property.

The lower easternmost mine workings are accessible by a dirt road that joins the Minnietta mine road west of Ash Hill, and the upper workings on Lookout Mountain by a steep dirt road, branching off from the Defense mine road, that is most easily negotiated with a 4-wheel drive vehicle (pl. 2). The upper workings are also accessible by a trail from the lower workings.

Table 5. Production of the Modoc mine.

(Compiled from files of the U. S. Bureau of Mines and published with permission of the mine owners.)

Year	Ore (dry tons)	Gold (ounces)	Silver (ounces)	Copper (lbs.)	Lead (lbs.)	Zinc (lbs.)
1875-1890 . .	Production totalled $1,900,000*					
1891	. .	196.98	65,016			
1892	. .	29.02	21,420			
1893	. .	32.41	24,872			
1897	. .	. .	10,017			
1945	10,766	35	42,966	95,635	1,723,800	
1946	3,891	59	19,960	27,972	573,177	
1947	501	24	4,646	3,029	54,724	
	19	2	502	75	2,050	4,740
1953	3	. .	107	12	1,356	633
Total . . 1891-1953	15,180	378	189,506	126,723	2,355,107	5,373

* From Crawford, 1894, p. 24, and Tucker and Sampson, 1938, p. 445.

The mine was discovered in 1875 according to Tucker and Sampson (1938, p. 445). The main period of production was by the Modock Consolidated Mining Company between 1875 and 1890, during which time the gross value of production was $1,900,000 (Crawford, 1894, p. 24). Since 1890 the production recorded by the U. S. Bureau of Mines has a gross value of about $450,000. Most of this was from reworking slag piles and mine dumps by L. D. Foreman and Co. from 1945 to 1947. The production is given in table 5.

The grade of ore mined during the 1870's and 1880's was very high. Crawford (1894, p. 24) wrote that the ore contains 101 to 293 ounces of silver per ton and 52 percent lead. Burchard (1884, p. 104) stated that the mine is extensively developed and large amounts of argentiferous lead ore have been extracted that averaged $60 to $80 (46 to 62 ounces) in silver. The dump and slag mined since 1944 averaged 7.8 percent lead and 4.5 ounces of silver per ton.

The mine is developed by over 8,000 feet of drifts and small stopes on four levels at altitudes of approximately 2,830, 3,390, 3,500, and 3,650 feet. Many of the stopes are now caved or filled. The upper workings explore two mineralized areas about 700 feet apart at the surface (pl. 7, photo 11). One area developed by the No. 2 and No. 3 tunnels is mineralized over a length of 600 feet and the western area, developed in part by the No. 4 tunnel, is mineralized for 500 feet. An adit 1,860 feet long was driven 565 feet lower than the No. 2 tunnel to explore possible downward extensions of ore bodies (pl. 7).

Geology. The mine area is underlain by the Lost Burro formation of Devonian age, which consists of white and light-gray thin- to medium-bedded marble and thinly bedded bluish-gray limestone. The ore deposits are in the white marble, which locally is stained brown or black by limonite or secondary manganese minerals and is in part altered to massive buff dolomite (pl. 7). The white marble is localized close to thrust faults. Elsewhere the Lost Burro formation is thinly bedded bluish-gray limestone.

The mine is on the northeast limb of a major anticline in the Modoc district (pl. 2). Bedding strikes predominantly north to N. 30° W. and dips 37° to 80° E. Locally small folds are present on the limb of the anticline. The trace of the axis of an open syncline is 50 feet west of the No. 2 tunnel and 120 feet west of the No. 3 tunnel (pl. 7), and the trace of an anticlinal axis is 200 feet east of the syncline.

The Paleozoic rocks have been disrupted by several faults, but the displacement probably is not large. The most important economically are flatly dipping faults. A highly fractured zone strikes northwest through the portal of the No. 2 adit and dips 10° to 40° SW. (pl. 7). Drag folds indicate this is a thrust zone; thinly bedded limestone under the thrust in the eastern part of the

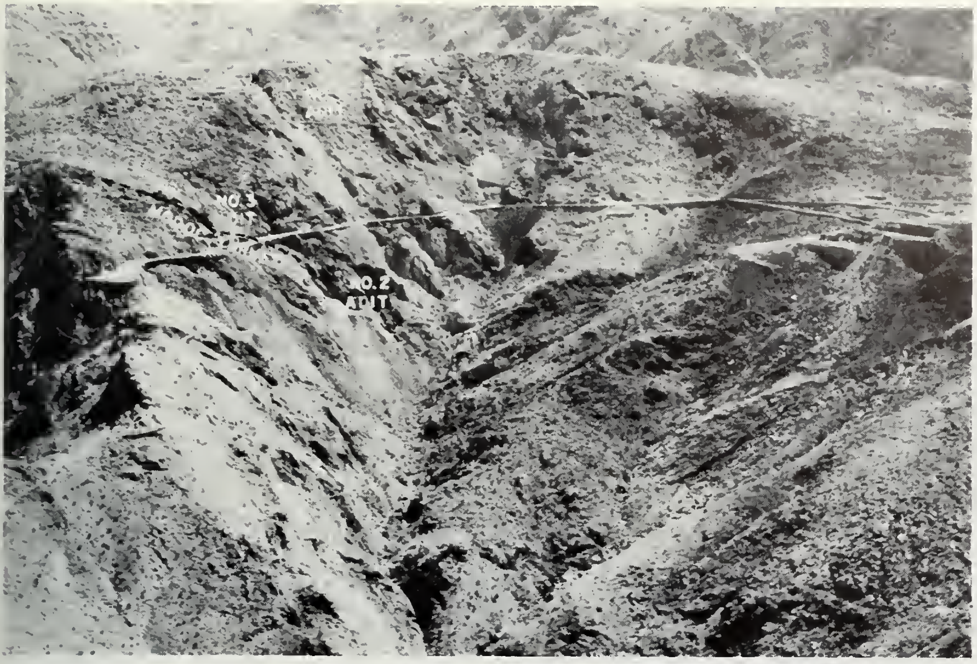

Photo 11. Aerial view southwest toward the upper workings of the Modoc mine. The Modoc thrust passes through the portals of the No. 2 and No. 3 adits, and much of the mineralization is in the footwall of it.

mine area is overturned by drag along the fault. The marble in this fractured zone is highly iron-stained and is in part dolomitized. Another flat mineralized zone is in the western part of the mine area and may be the same fault zone, which has been faulted up on the west. A steep mineralized fault is near the south end of the mapped area (pl. 7). It strikes about N. 70° E. and dips 50° to 60° S. The marble on the south side of this fault is altered to massive buff-colored dolomite.

Ore deposits. Very little ore is exposed in the mine now, but the size and distribution of stopes indicates that ore was mined from many small ore bodies that were rather widely spaced. Ore occurs as tabular bodies in a thrust zone and as an irregular pipelike body in or near a steep northeast-striking fault.

Two mineralized areas are in a thrust zone in the upper workings. One area is a fractured zone under a thrust fault in the northeastern part of the mine area and the other is in the western part under a thrust (pl. 7). In the eastern area the marble host rock is extensively iron and manganese stained and is in part dolomitized. Many small open cuts have been dug in the most strongly mineralized parts and winzes connect some to the No. 2 and No. 3 levels (pl. 7). Two ore bodies were mined that lie just under the thrust and dip 12° W. parallel to it. Ore body No. 3 (section A-A′, pl. 7) was mined discontinuously from the open pit for 160 feet to the No. 3 level. The country rock is white and light-brown marble that is locally iron and manganese stained. The ore body is accessible in the open cut at the portal of the No. 3 adit, but the adit is filled about 60 feet beyond the open cut and the size of the stopes is not known.

Ore body No. 2 is 80 feet below No. 3. It is 140 feet long, 10 to 60 feet wide, and 20 to 30 feet thick. The ore body is on the east side of a steep N. 8° W-striking pre-mineral fault (sec. A-A′, pl. 7), and is localized by flat fractures parallel to the overlying thrust fault. The margins of the stope contain small pockets of galena, cerussite, bindheimite, and secondary copper minerals in a powdery limonite and wad matrix. The country rock is white and yellowish-brown marble.

Some ore has been mined near the portal of the No. 2 adit. The marble country rock is highly iron and manganese stained and in part dolomitized for 120 feet northwest from the portal. A small gently dipping ore body was mined from an inclined slope 30 feet from the portal of the No. 2 adit on the east side of a steep N. 30° W.-trending fault (pl. 7). A small amount of ore was probably mined from the open cut 120 feet northwest of the portal of the No. 2 adit in a highly manganese-stained fault dipping 28° W.

The second mineralized area is in the western part of the mine area on the footwall of a gently westward dipping fault. Many small pits and several winzes and adits explore the most heavily iron- and manganese-stained marble (pl. 7). A small ore body (No. 5) was mined from the Modoc tunnel, about 100 feet below the thrust (sec. C-D-E, pl. 7). Some ore also was probably mined from the open cut and winzes about 280 feet south of the portal of the Modoc tunnel (pl. 7).

Most of the ore from the mine has come from the No. 4 ore body in a third mineralized area in the southern part of the mine area south of a steep N. 70° E.-striking fault (secs. B-B′ and C-D-E, pl. 7). The country rock is massive buff-colored dolomite. The ore has come principally from above the No. 3 level in or near a fault that strikes N. 50° E. and dips 55° to 70° SE. The No. 4 ore body is 180 feet long, 5 to 35 feet thick, and has been mined 160 feet down the dip. The ore body rakes 45° S. It may extend to the No. 2 level. Some stoping was done at the south end of the No. 2 level where the No. 4 ore body would project, but the stope is caved and it is not known how much ore was mined here.

Little is known about the mineralogy of the Modoc ore as very little ore is visible even at the margins of stopes now. Much of the material on the dumps and the marble near stopes contains considerable manganese similar to that at the Minnietta mine. Coronadite and cryptomelane probably were present in some of the oxidized surface ore bodies in the western part of the mine area, similar to that at the Defense mine.

A small amount of ore at the margin of the No. 2 ore body (sec. A-A′, pl. 7) contains relict galena in a matrix of cerussite, pyrolusite, limonite, calcite, and minor caledonite and linarite. Galena is the predominant ore mineral at the margin of the No. 1 ore body.

Paul Imlay prospect

The Paul Imlay prospect is in the Modoc district in and on the north side of Stone Canyon about half a mile N. 35° W. of French Madam spring at an altitude of about 5,040 feet (pl. 2). The mine workings total about 110 feet of adits. The main adit is in a tributary canyon about 750 feet north of the jeep road that extends over the crest of the Argus Range from the Modoc district to Darwin, California. A steep road leads to this adit from the jeep road in Stone Canyon. The prospect is owned by Mrs. Paul Imlay of Lone Pine, California. No production is known from the property.

The main adit is in white marble of the Lee Flat limestone, immediately north of an east-trending fault contact between overturned beds of the Perdido formation to the south and Lee Flat limestone to the north (pl. 2). The Perdido formation is intruded by many small bodies of hybrid quartz monzonite and is in large part altered to calc-silicate rock.

The main adit follows a small fault that strikes east and dips vertically. Sixty feet from the portal of the adit a short crosscut follows a mineralized fault that strikes N. 20° W. and dips 44° SW. The mineralized rock consists of white marble locally replaced by dark-brown or black iron and manganese oxides and containing some azurite and malachite.

Red Dog prospect

The Red Dog prospect is located immediately north of the road in Osborne Canyon in sec. 18 (proj.), T. 19 S., R. 42 E. about 1 mile N. 29° E. of the Surprise mine (pl. 1).

W. G. Osborne and W. J. Osborne are the owners of the claim. The workings consist of two open cuts about 15 feet deep. They expose a vein less than 1 foot thick that strikes N. 60° W. and dips 34° NE. The vein is in leucocratic quartz monzonite and is exposed for 40 feet. It contains minor green copper-bearing minerals and some cerussite. According to J. Grant Goodwin (1957, p. 504), a small shipment in 1948 contained 14.4 percent lead, 51.9 ounces of silver and 0.30 ounce of gold.

Surprise mine

The Surprise mine is in the Modoc district on the eastern flank of the Argus Range in sec. 19 (proj.), T. 19 S., R. 42 E. at an altitude of 4,600 feet (pl. 2). It is about half a mile south of Osborne Canyon and is connected by 7 miles of gravel road to the hard-surfaced county road in Panamint Valley, which leads from State Highway 190 to Trona (fig. 1).

The mine was located in 1941 by Jesse L. Osborne and Sam Slater. The property consists of three unpatented claims owned at present by A. L. Foss and Marie Osborne Keck of Beverly Hills, California. It is developed by about 1,600 feet of underground workings—principally on the Zero or main level and on the 50-feet level (pl. 8).

Between 1942 and 1951, 940 tons of ore was shipped which averaged 29.6 percent lead, 24.4 ounces of silver per ton, and 0.08 ounce of gold per ton. A 35-ton shipment made in 1945 contained 13.2 percent zinc. Other shipments did not record zinc content. All of the ore that has been shipped came from the vacinity of the Zero level or workings connected with it. The annual production is tabulated below in table 6.

Table 6. Production of lead-silver ore from the Surprise mine.

(Production data provided by the mine owners and published with their permission.)

Year	Ore (dry tons)	Lead (lbs.)	Zinc (lbs.)	Gold (ozs.)	Silver (ozs.)
1942...	10	6,090	..	4.30	162.50
1945...	35	14,490	9,240	1.75	183.75
1947...	314	178,792	..	25.12	7,008.48
1948...	277	161,990	..	21.61	6,786.50
1949...	150	104,400	..	11.40	4,452.00
1950...	48	29,693	..	4.56	1,481.28
1951...	106	60,717	..	9.12	2,834.44
Total.	940	556,172	9,240	77.86	22,908.95

Geology. The Surprise mine area is underlain by the Tin Mountain limestone of Early Mississippian age (pl. 9). The Tin Mountain limestone consists mainly of fine-grained, thin- to medium-bedded, gray limestone. Locally chert lenses and nodules are present. Much of the limestone is bleached and brecciated near faults.

The Tin Mountain limestone is intruded by several small bodies of diorite and altered quartz monzonite (secs. A-A′ and B-B′, pl. 9) and by a felsic dike in the southern part of the mine area. Three small bodies of quartz monzonite crop out 0.3 miles west of the mine area, and a quartz monzonite stock crops out a mile north of the mine (pl. 1).

The Surprise mine area is on the axis of a N. 20° W.-trending anticline, which is the major structural feature of the northern Argus Range (pl. 1). The Tin Mountain limestone forms the core of the anticline, and the younger Paleozoic beds form conformable arcuate bands toward the west, north, and east (pl. 2). Bedding strikes northwest, and dips southwest in the southwestern part of the mine area and northeast in the northern part except for several minor folds on the east limb of the major anticline (pl. 9).

Two sets of steep faults predominate—one striking about N. 70° E. and the other approximately northwest (pl. 9). All the ore mined to date has been close to one of the N. 70° E. faults. The amount or direction of displacement on the faults is not known because of the lack of marker beds. A flatly dipping mineralized fault of little displacement was followed by the 22-foot level in the southern part of the mine area, but it contained little ore (pl. 8).

Ore deposits. High-grade lead-silver ore occurs in small steeply dipping bodies in the hanging wall of a fault that strikes about N. 70° E. and dips steeply southeast. The ore is localized by highly brecciated rock near the intersection of tightly folded Tin Mountain limestone and the fault striking N. 70° E. to east. The mineralized area is 60 feet long in a N. 70° E. direction, about 8 feet wide, and extends from the surface to the 50-foot level, a distance of 75 to 90 feet (secs. A-A′ and B-B′, pl. 9). The ore bodies had irregular, pipelike, or tabular shapes and plunged 60° to 80° S. Contacts of ore with bluish-gray limestone host rock are sharp. Very little ore is exposed in the workings now.

The ore bodies contained both primary and secondary ore minerals. Argentiferous galena is the principal ore mineral. It is in part oxidized to cerussite, mimetite, and pyromorphite. Commonly cores of relict galena are surrounded by cerussite and an outer shell of olive-green to yellowish-green spongy mass of mimetite and pyromorphite. Sphalerite, chalcopyrite, and pyrite are less abundant primary ore minerals. Locally azurite, chrysocolla, and malachite stain fractures. Little gangue is present in the ore bodies, but some calcite, chalcedony, jasper, and clay minerals are associated with ore.

Mines and prospects in the Panamint Range

Big Four mine

The Big Four mine is in the Panamint Butte quadrangle near the northeast end of Panamint Valley in sec. 26, T. 17 S., R. 42 E. at an altitude of 2,600 feet. It is situated at the base of the west slope of the Panamint Range about 7 miles north of State Highway 190. An unimproved gravel road connects the mine with the highway.

The mine was first located in 1907, according to Norman and Stewart (1951, p. 57), but the original ownership is not known. Three claims, located by William Reid in 1940, were owned in 1957 by Mrs. Agnes Reid, Panamint Springs, California; Silas Ness, Olancha, California; William Braun, Bishop, California; and Marie Keck, Los Angeles, California.

Between November 1944 and August 1952, 470 tons of ore were mined which averaged 16.6 percent lead, 12.5 percent zinc, and 2.6 ounces of silver per ton. The annual production provided by the mine owners is given in table 7.

Table 7. Production of lead-silver-zinc ore from the Big Four mine.

(Data provided by mine owners and published with their permission.)

Year	Tons of ore	Lead (lbs.)	Zinc (lbs.)	Silver (ozs.)
1944....	44.72	14,668	21,644	178.9
1945....	288.70	107,855	63,486	637.9
1952....	136.78	33,349	32,074	400.2
Total....	470.20	155,872	117,204	1,217.0

The mine is developed on three levels (pls. 10, 11). The upper level at an altitude of 2,700 feet consists of a short adit and several small bedding-plane stopes within 40 feet of the portal. Most of the ore was mined from the intermediate level, which contains a short adit and about 600 square feet of stopes. An adit 540 feet long 170 feet below the intermediate level did not expose any ore.

Three prospect pits, or short adits, are approximately 3,000 feet N. 65° W. of the main workings. They expose a small pod of ore that produced about 2 tons of lead ore.

Geology. The Big Four mine area is underlain by the Pogonip group(?) of Early and Middle(?) Ordovician age, the Keeler Canyon formation of Pennsylvanian and Permian age, and at the north end of the mine area by an extensive basaltic talus (pl. 10). The Pogonip group(?), the oldest formation exposed in the mine area, is in a thrust sheet overlying the Keeler Canyon formation. It consists of medium- to thick-bedded, white, buff, and gray dolomite, dolomitic marble, limestone, and in the eastern part of the mine area, a thin bed of brownish-gray siltstone. No fossils were found in the Pogonip(?) and the assignment was made on the basis of lithology.

The Keeler Canyon formation consists of a lower unit of thin- to medium-bedded, bluish-gray limestone locally bleached and recrystallized to marble and an upper marble unit. The marble unit is thickest at the north end of its outcrop and is progressively thinner to the southeast to a point 120 feet southeast of the intermediate workings where it is nearly cut out by the thrust. The marble thickens again to the southeast but is only slightly mineralized. Much of the marble unit is dolomitized. The Keeler Canyon formation is intruded by two small diorite dikes near the floor of the canyon.

The major structural feature in the mine area and the dominant ore controlling structure is the thrust fault exposed at the portal of the intermediate workings (sec.

A-A′, pl. 10). It is part of the Lemoigne thrust in the northeast part of the Panamint Butte quadrangle (pl. 1). The thrust strikes about N. 35° W. and dips 30° NE. Bedding above the thrust approximately parallels the thrust fault, but bedding in the Keeler Canyon formation dips more steeply and is discordant.

Ore deposits. Lead-silver-zinc ore occurs in small, tabular replacement bodies roughly parallel to bedding in or near the Lemoigne thrust. The thrust is mineralized for about 300 feet along the outcrop, but the distribution of ore is mainly in the vicinity of the intermediate level (pl. 11). The intermediate workings have about 1,300 square feet of stopes that average 3 to 4 feet high.

Very little ore is visible in the workings except some low grade south of the portal of the intermediate adit. Apparently most of the ore was oxidized and consisted of a dark-red and reddish-brown fine-grained mixture of cerussite, hemimorphite, relict specularite, hematite, and jasper. Primary ore was seen only in the prospect 3,000 feet northwest of the main workings where a pod of galena was mined.

Kerdell prospect (Lone Ear prospect)

The Kerdell prospect is located in the Panamint Range in the northeastern part of the Panamint Butte quadrangle 1.8 miles S. 18° E. of the Lemoigne mine at an altitude of 5,800 feet. According to claim notices the property was relocated as the Lone Ear claim on December 10, 1954, by Roy Hunter. The prospect is accessible by a trail about 6 miles long that takes off from the Lemoigne road about 1,000 feet below the mouth of Lemoigne Canyon at a place where the road has been widened for parking and turning around. The trail forks at the mouth of the canyon 1¼ miles southeast of the mouth of Lemoigne Canyon and one branch goes up the canyon to the prospect and the other fork goes to the Emigrant Ranger station (fig. 1, pl. 1).

The property is described as the Kerdell lead mine by Norman and Stewart (1951, p. 72-73). They state it consists of 12 unpatented claims owned by the Gold Hill Dredging Co., 311 California Street, San Francisco, Calif. Work on the property was started in March 1949, and workings consist of two adits and drifts totaling 300 feet. Supplies including water must be packed in. No production is known from the property.

The prospect is in the Keeler Canyon formation of Pennsylvanian and Permian age about 60 feet below a thrust fault contact with overlying dolomite of Cambrian age. The Keeler Canyon formation consists of thin- to medium-bedded limestone with abundant dark-brown chert nodules 1 to 2 inches in diameter. The limestone is strongly sheared in a direction N. 70° E., dipping 18° N. parallel to the thrust fault. Bedding and shearing of the limestone in the mine area are parallel, but bedding several hundred feet from the thrust strikes northward and dips 20° to 40° E. The sheared limestone is mineralized locally in the vicinity of the adits and contains disseminated limonite and some disseminated oxidized copper and lead minerals.

Lemoigne mine

The Lemoigne mine is in Death Valley National Monument on the east slope of the Panamint Range at an altitude of 5,000 feet in the South Fork of Lemoigne Canyon, 13.4 miles S. 44° W. of Stovepipe Wells. An unimproved, winding gravel road 5 miles long connects the mine with the mouth of Lemoigne Canyon and then extends northeastward across the alluvial fan to State Highway 190 between Emigrant Ranger station and Stovepipe Wells. The mine is accessible to passenger cars, although parts of the road are rough and deeply rutted.

According to Bev Hunter of Lone Pine, California, the mine was discovered in 1918 by John Lemoigne. Bev Hunter obtained the property in 1919, and is the current owner. The Buckhorn Humboldt Mining Company bought the property in 1920 and shipped some ore in 1925 and 1927. Hunter refiled on the property later, and leased it to W. V. Skinner of Lone Pine, who produced some ore during 1953.

The total production has a gross value of about $38,000. The production totals about 600 tons that contained approximately 30 percent lead, 7 percent zinc, and 4 ounces per ton in silver. The annual production is given in table 8. The production data for 1925, 1927, and 1947 are from the files of the U. S. Bureau of Mines. Subsequent data are from Bev Hunter.

Table 8. Production of lead-silver-zinc ore from the Lemoigne mine.

(Production data for 1925, 1927, 1947 from files of the U. S. Bureau of Mines. Published with permission of the mine owners.)

Year	Tons ore (dry)	Gold (ounces)	Silver (ounces)	Lead (lbs.)	Zinc (lbs.)
1925...	150	6.55	875	147,986	
1927...	80	113.76	397	20,500	
1947...	3	..	19	2,746	
1948...	2.6	.05	19	2,669	
1953...	370.5	7.87	1,088	198,926	52,246
Total.	606	128.23	2,398	372,827	52,246

The mine is developed by about 500 feet of workings on three levels and one sublevel connected by a vertical shaft, and by three gently dipping stopes (pl. 12). Ore was also stoped around the shaft between altitudes of 5,070 and 5,095 feet (sec. A-A′, pl. 12). The shaft is about 80 feet deep, but does not extend to the surface.

Geology. The Lemoigne mine area is underlain by gray, medium-bedded dolomite of probable Cambrian age. No fossils were found, but the dolomite lithologically resembles the Racetrack dolomite of Middle and Late Cambrian age. The dolomite weathers to a sandy texture or to one that is rough and hackly. Locally the dolomite is bleached and highly shattered near faults.

Bedding in the mine area strikes northward and dips both east and west in an open anticline and syncline (pl. 12). The dolomite is cut by a series of steep faults striking about N. 20° E. The faults are conspicuous shear zones at the surface, but appear quite tight in underground workings.

Ore deposits. Very little ore is exposed in the mine workings, but the stopes and production record show that ore occurred in small, high-grade ore bodies. Most of the ore came from the stope at the end of the 5,040 level (pl. 12). The ore body is a bedding plane replacement that is 60 feet long down the dip, 5 to 15 feet wide, and 5 to 10 feet high. The ore body was in part controlled by bedding plane fractures that strike N. 40° E. and dip 20° to 30° NW. A little galena and cerussite remain in the back of the stope, and some siliceous silver ore with encrustations of chrysocolla is exposed in the upper, southeast end of the stope (sec. B-B′, pl. 12).

Some ore was mined from the main shaft above the 5,070 level (pl. 12). The ore apparently occurred as a steep pipelike body along a fault striking northwest and dipping 65° NE.

No zinc minerals were seen in the small amount of ore observed underground, but some specimens of secondary ore containing hydrozincite were observed on the dump.

URANIUM DEPOSITS

Considerable prospecting was done for uranium in the northern part of the Argus Range during the period of intensive search for radioactive minerals in California during the early 1950's, but very little was found. A few small pockets containing radioactive minerals were explored near intrusive contacts in the vicinity of Osborne Canyon (pl. 1). The most extensive radioactivity is on the Golden Nugget prospect in Osborne Canyon (pl. 1).

Golden Nugget prospect

The Golden Nugget prospect is 1.4 miles N. 54° W. of the Surprise mine in Osborne Canyon at an altitude of 4,670 feet. It is reached by a trail up Osborne Canyon from the road to the Surprise mine (pl. 1). The prospect was examined by Harry E. Nelson of the U. S. Atomic Energy Commission on May 13, 1955. He collected a channel sample over a thickness of one foot that contained 0.329 percent U_3O_8 (written communication, 1956). At that time the prospect was owned by Alice B. Malcon of Santa Monica, Calif., John Moranke of South Gate, Calif., and Fred Gibbens of Redondo Beach, Calif. Claim notices in 1959 now call this the Polaris group.

The prospect is on the north side of the Osborne Canyon fault along a fault in cherty limestone of the Perdido formation of Mississippian age (pl. 1). The fault trends N. 5° W. and dips 70° W. A sheared zone in or near the fault is replaced by jasper and some disseminated copper minerals. The zone with jasper is about 200 feet long and a maximum of 60 feet thick. Locally the sheared zone is dolomitized.

At the north end of the zone of dolomitized limestone and jasper is a mineralized fault containing radioactive minerals that strikes N. 85° W. and dips 35° N. An open cut 15 feet long and 10 feet wide exposes a vein 3 feet thick that contains disseminated secondary copper minerals, pyrolusite, limonite, and torbernite(?) for a strike length of 50 feet. The average radioactive count of the vein is 0.02 MR/hour against a background of 0.0015 MR/hour. The maximum count is 0.075 MR/hour in local yellowish-brown spongy limonitic pods. The source of the uranium was not identified, but a green mineral may be torbernite.

GOLD DEPOSITS

The production of gold from the Panamint Butte quadrangle and the Modoc district is small, totalling slightly over 2,500 ounces. The gold comes mainly from small amounts in the lead-silver ore, but some has come from gold-quartz veins. Lead ore at the Surprise mine averaged 0.08 ounces of gold per ton of ore, and at the Defense mine 0.0125 ounces per ton. Ore mined in recent years from the Minnietta mine similarly contained only a few hundredths of an ounce of gold per ton, but the early production record shows a much higher gold content from the Minnietta, averaging more than 0.4 ounces of gold per ton between 1902 and 1916 (table 4). It seems unlikely that the oxidized lead-silver ore mined then was that much richer in gold than the ore mined more recently from the Defense and Minnietta mines, and probably some of this gold actually came from nearby gold properties.

The Little Mack is the only mine in the area that has a known recorded production for gold alone. Other gold prospects are in or near quartz monzonite or alongside andesite porphyry dikes, but if they had a production it was lumped with the lead-silver mines or was not recorded.

Little Mack mine

The Little Mack mine is in Thompson Canyon 400 feet east of the housing at the Minnietta mine at an altitude of 2,800 feet (pl. 2). The mine was operated by Otto Siedentopf of Trona, Calif., who produced $15,000 in gold between 1930 and 1937 (Tucker and Sampson, 1938, p. 405). No production is recorded with the U. S. Bureau of Mines since that time.

The mine area is underlain by white to light-gray marble of the Lost Burro formation of Devonian age, which is intruded by a series of parallel altered andesite porphyry dikes. Bedding in the Lost Burro formation strikes N. 5° E. and dips 40° W.; the dikes strike N. 74° W. and dip 50° SW. An adit trends N. 74° W. on the hanging wall of a dike for 250 feet according to Tucker and Sampson (1938, p. 404), and gold occurs at intersections of the dike with quartz veins that are parallel to bedding.

NONMETALLIC DEPOSITS

Nonmetallic commodities present in the Panamint Butte quadrangle include limestone, dolomite, and limy clay. Limestone is abundant in the Argus Range and dolomite in the Panamint Range (pl. 1).

Limestone

Formations containing fairly pure limestone or marble include the Lost Burro formation at Lookout Mountain and the Tin Mountain limestone and Lee Flat limestone present near Stone Canyon (pl. 2). The Keeler Canyon formation of Pennsylvanian and Permian age and Owens Valley formation of Permian age contain tremendous reserves of silty limestone.

The only analysis made was of a composite sample of marble taken at 5-foot intervals across the strike of the Lee Flat limestone on the east flank of the Argus Range along a ridge on the north side of Stone Canyon 1.34 miles N. 83° E. of the southwest corner of the quadrangle. A measured section was 750 feet thick. The sample is light-gray to white medium-grained marble. The analysis is as follows:

	Percent
SiO_2	.32
Al_2O_3	<.1
Total Fe as FeO	.10
MgO	.42
CaO	55.4
Na_2O	.06
K_2O	.02
TiO_2	.01
P_2O_5	.00
MnO	.00
H_2O	.08
CO_2	43.8
	100.3

Analysts, Paul L. D. Elmore and Samuel D. Botts, U. S. Geological Survey.

Dolomite

Dolomitic formations include the Racetrack dolomite and Nopah formation of Cambrian age, Pogonip group and Ely Springs dolomite of Ordovician age, and the Hidden Valley dolomite of Devonian and Silurian age, which make up much of the west face of the Panamint Range for a distance of 4 miles to the north of California State Highway 190 (pl. 1). The dolomite is of no interest commercially as large quantities of similar material are available much closer to market and rail transportation, for example, on the east side of Owens Valley at the foot of the Inyo Mountains.

Clay

Silty calcareous clay crops out in the southwestern part of the playa in Panamint Valley (pl. 1). Numerous shallow pits near the road to Trona in Panamint Valley 4.4 miles S. 63° E. of Panamint Springs expose white calcareous clay and silty limestone. A drill hole was put down by the Brown Mud Company of Bakersfield, California, to explore the clay, but the writers do not know the depth of the hole and have not seen a log of the hole. In 1953 a core hole 375 feet deep was drilled for the U. S. Geological Survey in the northern end of the playa (see pl. 1 for location), and a log of the hole is given by Smith and Pratt (1957, p. 54-57). The core was predominantly interbedded sand and silt to a depth of 80 feet and below that was interbedded clay, gravel, marl, sand, and silt. Bedrock was at a depth of 365 feet, and the last 10 feet of core was in limestone of Paleozoic age.

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THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF CONSERVATION

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SPECIAL REPORT 73
PLATE 1

EXPLANATION

QUATERNARY

Qal — Younger alluvial deposits
Includes valley fill, fanglomerate, sand dune deposits, and lake sediments

TERTIARY AND QUATERNARY

QTb — Basalt
Andesitic and basaltic flows and agglomerate

QTr — Rhyolitic tuff

QTa — Older alluvium
Includes tilted fanglomerates and associated monolithologic breccias

CRETACEOUS(?)

Kan — Andesite porphyry dikes
Some gold deposits in the Modoc district are associated with these dikes

JURASSIC(?)

Jqm — Quartz monzonite sequence

PENNSYLVANIAN AND PERMIAN

PPs — Silty limestone sequence
Predominantly thinly bedded silty and shaly limestone. Includes the Owens Valley formation of Permian age and the Keeler Canyon formation of Permian and Pennsylvanian age

DEVONIAN, MISSISSIPPIAN AND PENNSYLVANIAN(?)

CDm — Marble sequence
Predominantly marble, pure limestone, and cherty limestone. Marble is locally dolomitized or altered to calc-silicate rock near intrusive contacts. Includes the Lee Flat limestone of Pennsylvanian(?) and Mississippian age, the Perdido formation and Tin Mountain limestone of Mississippian age, and the Lost Burro formation of Devonian age. All the lead-silver deposits in the Modoc district are in this unit

CAMBRIAN, ORDOVICIAN, SILURIAN AND DEVONIAN

DCd — Dolomite sequence
Predominantly dolomite but includes some quartzite and limestone. Includes the Hidden Valley dolomite of Silurian and Devonian age; Ely Springs dolomite, Eureka quartzite, and Pogonip group of Ordovician age; and Nopah formation and Racetrack dolomite of Cambrian age

PRECAMBRIAN(?) AND CAMBRIAN(?)

Gn — Gneissic sequence
Includes quartz-mica schist, hornblende gneiss, quartzite, and dolomite

Contact
Dashed where approximately located

Fault, showing dip
Dashed where approximately located; dotted where concealed. U, upthrown side; D, downthrown side

Thrust fault
Sawteeth on side of upper plate

Strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds

Strike and dip of flow layering

Lead-silver prospect

Lead-silver mine with recorded production

Uranium prospect

Pit in calcareous clay

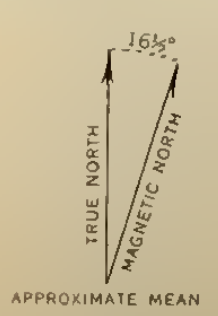
Spring

Jeep trail

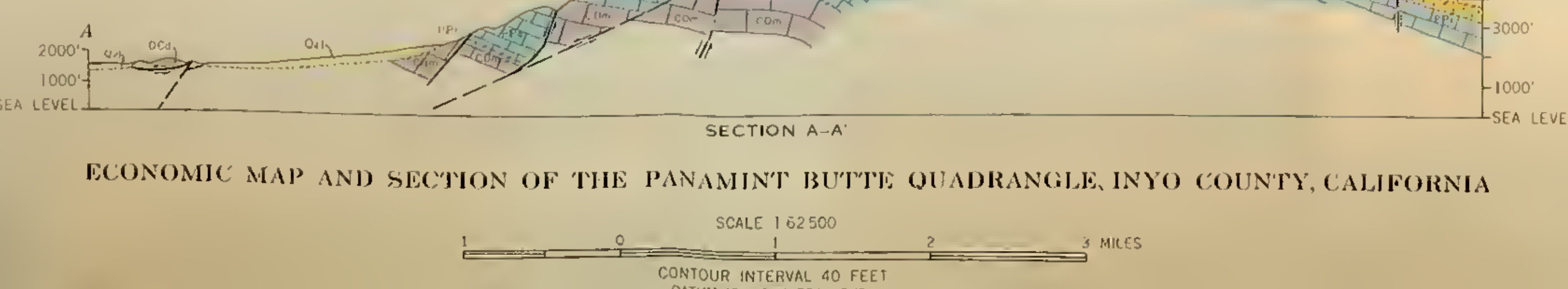
Base map by Topographic Division, U. S. Geological Survey

Geology by W. E. Hall and H. G. Stephens 1956-58

Williams & Heintz Map Corporation, Washington 27, D. C.



APPROXIMATE MEAN DECLINATION, 1961



SECTION A-A'

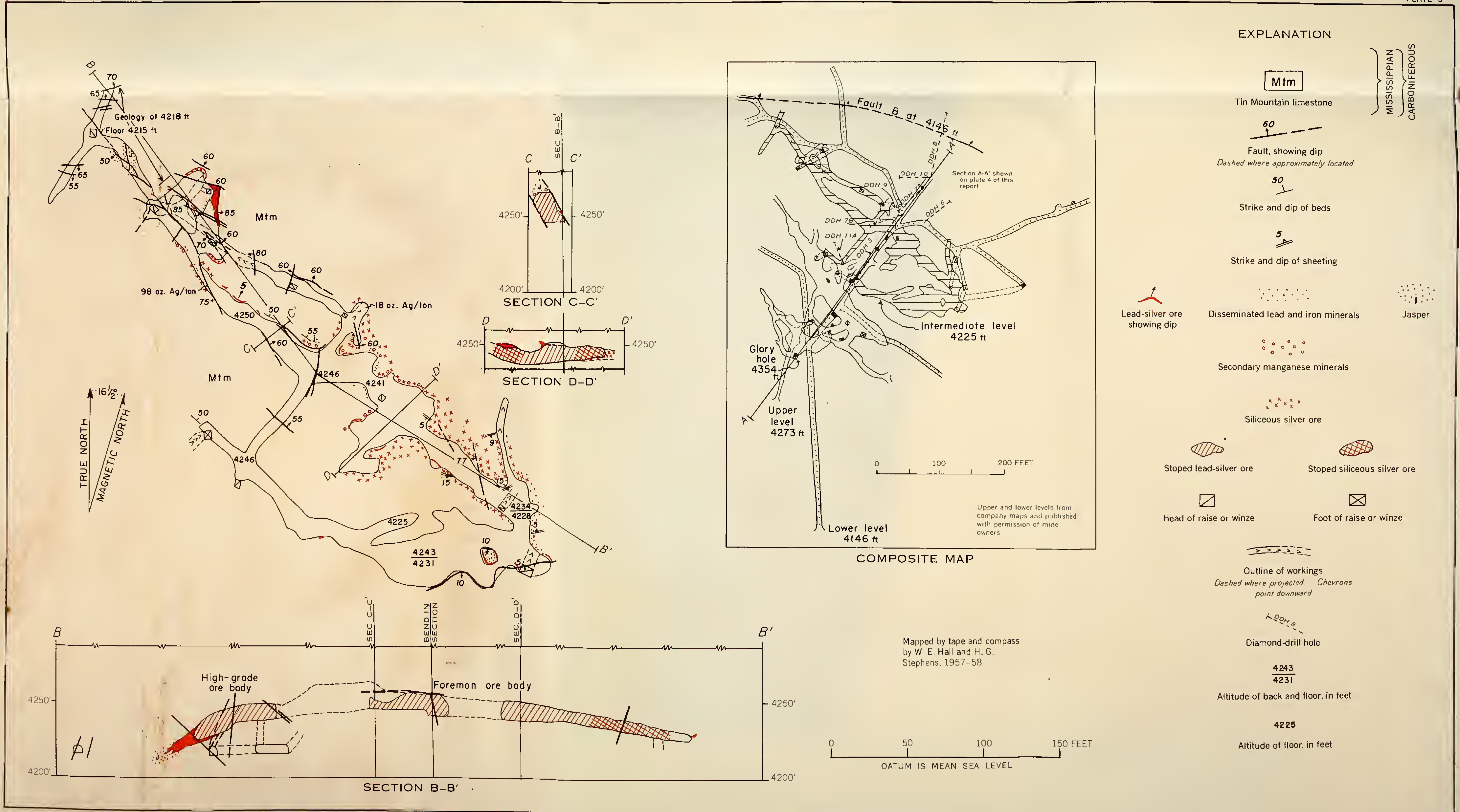
ECONOMIC MAP AND SECTION OF THE PANAMINT BUTTE QUADRANGLE, INYO COUNTY, CALIFORNIA

SCALE 1:62500

1 0 1 2 3 MILES

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

GEOLOGIC MAP OF THE MODOC DISTRICT, INYO COUNTY, CALIFORNIA



GEOLOGIC MAP AND CROSS SECTIONS OF THE INTERMEDIATE WORKINGS OF THE DEFENSE MINE INYO COUNTY, CALIFORNIA

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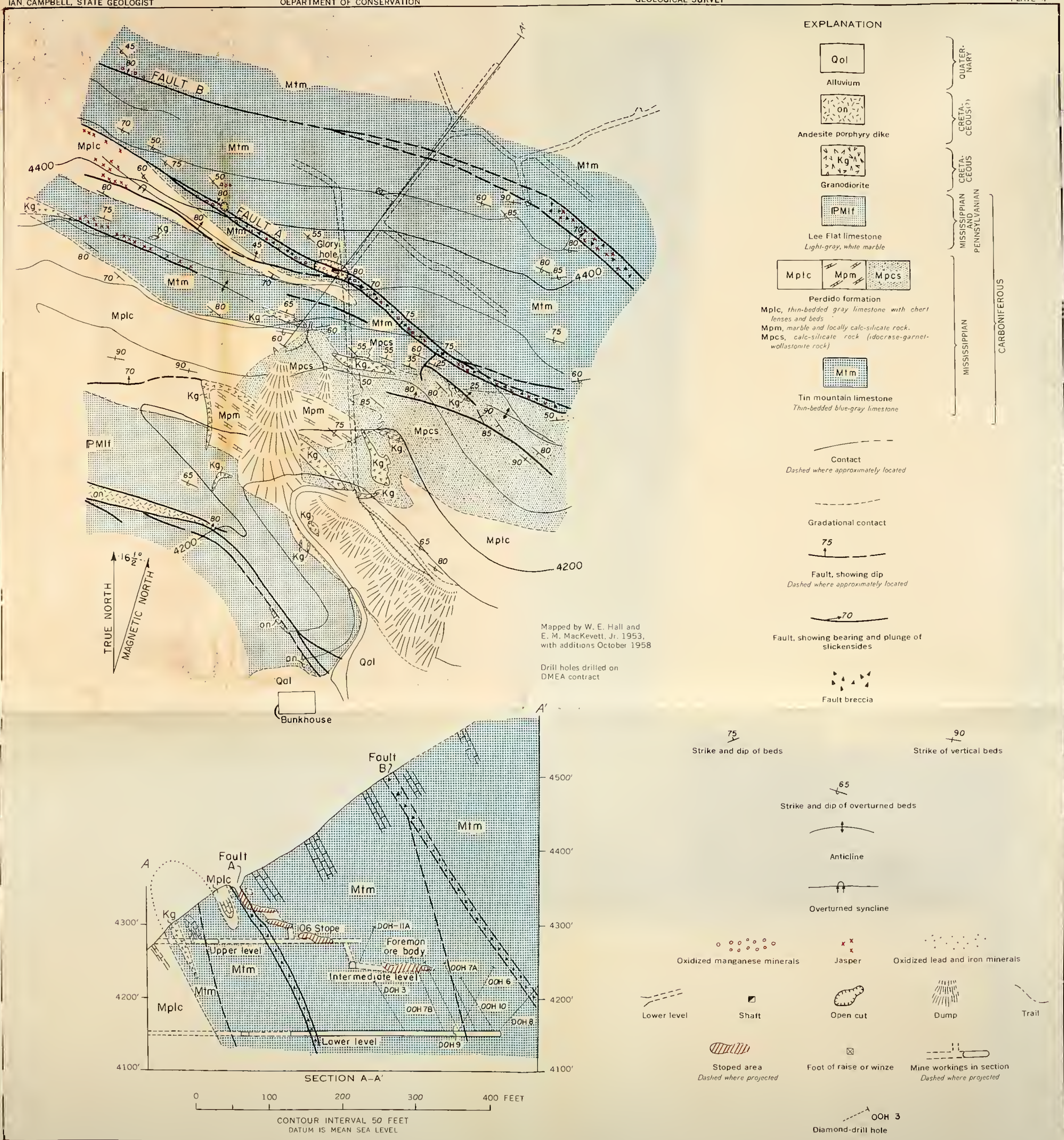
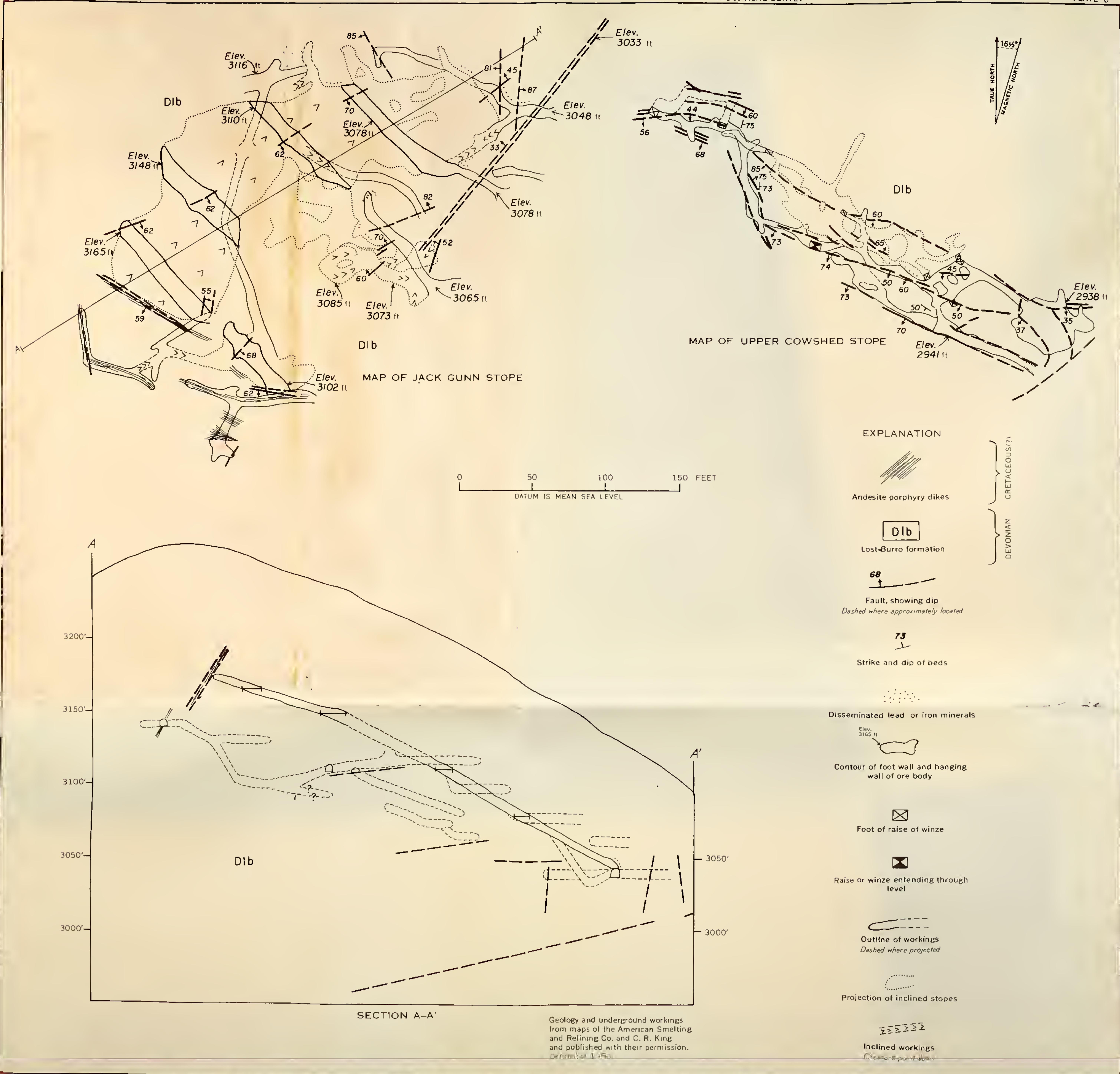
PLATE 4



GEOLOGIC MAP AND SECTION OF THE DEFENSE MINE, INYO COUNTY, CALIFORNIA

GEOLOGIC MAP AND SECTION, MINNIETTA MINE, JACK GUNN AND COWSHED WORKINGS, INYO COUNTY, CALIFORNIA



GEOLOGIC MAP AND SECTION OF THE JACK GUNN AND UPPER COWSHED STOPES, MINNIETTA MINE, INYO COUNTY, CALIFORNIA

GEOLOGIC MAP AND SECTIONS OF THE MODOC MINE, INYO COUNTY, CALIFORNIA

GEOLOGIC MAP OF UNDERGROUND WORKINGS, SURPRISE MINE, INYO COUNTY, CALIFORNIA

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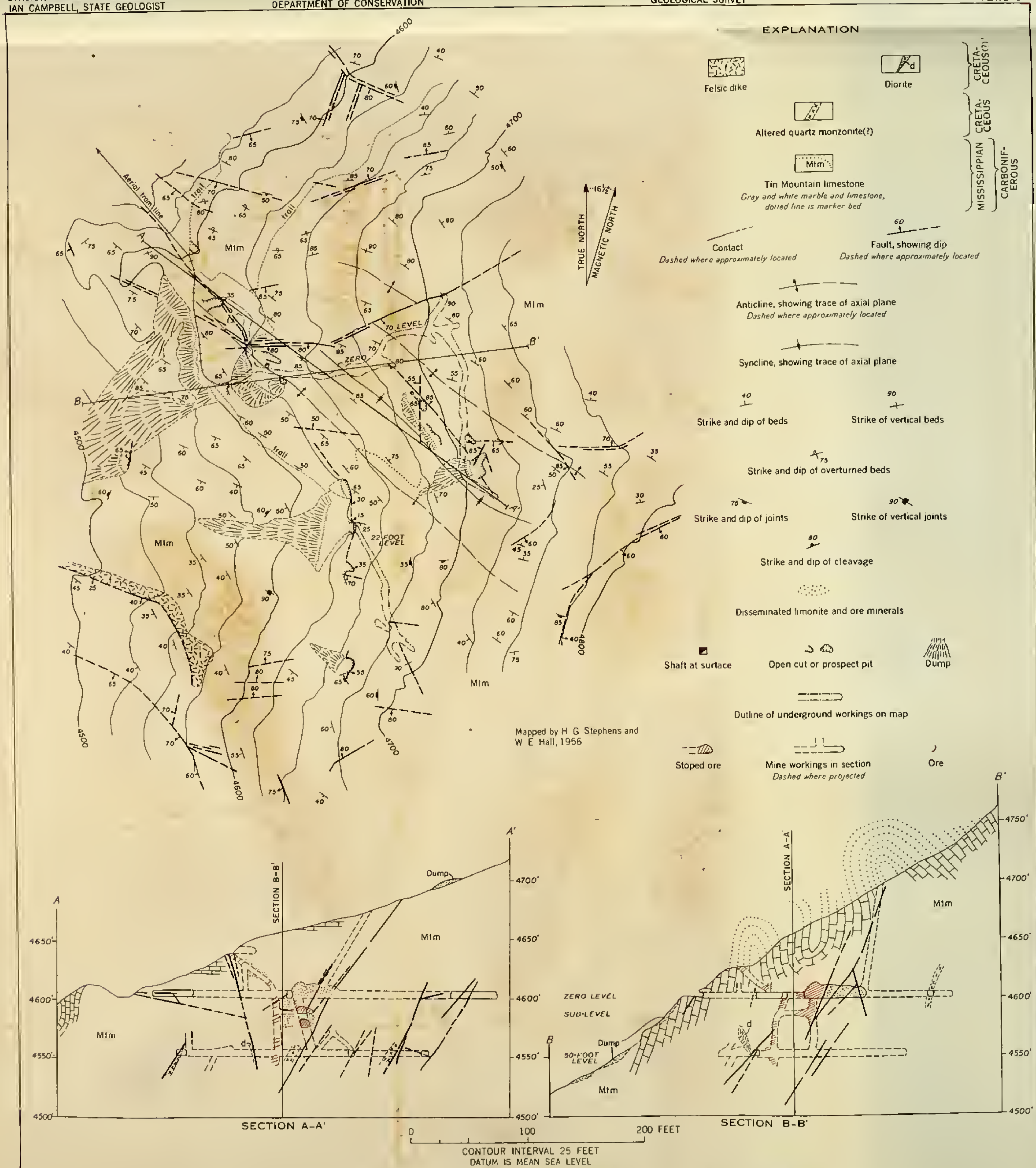
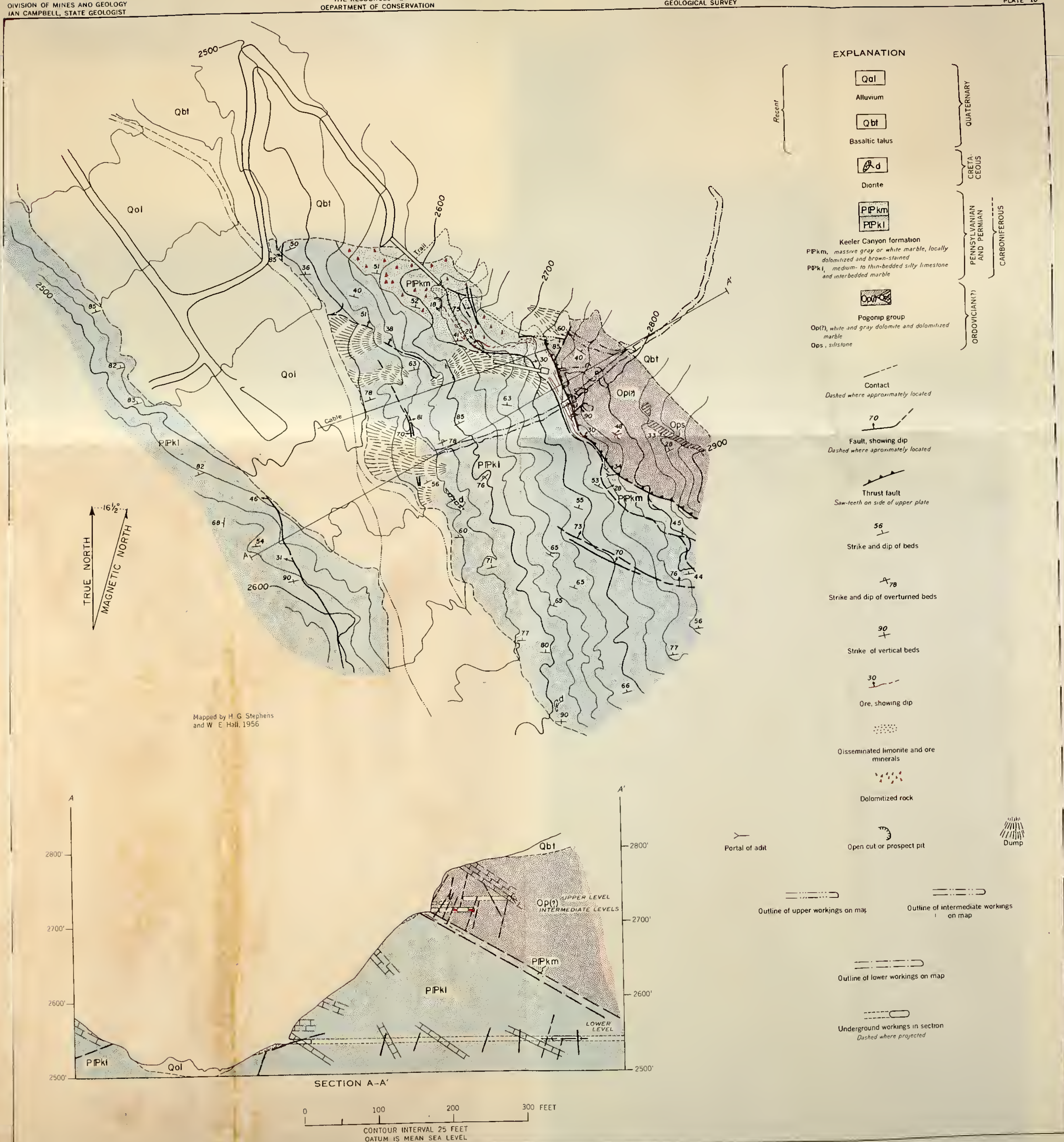
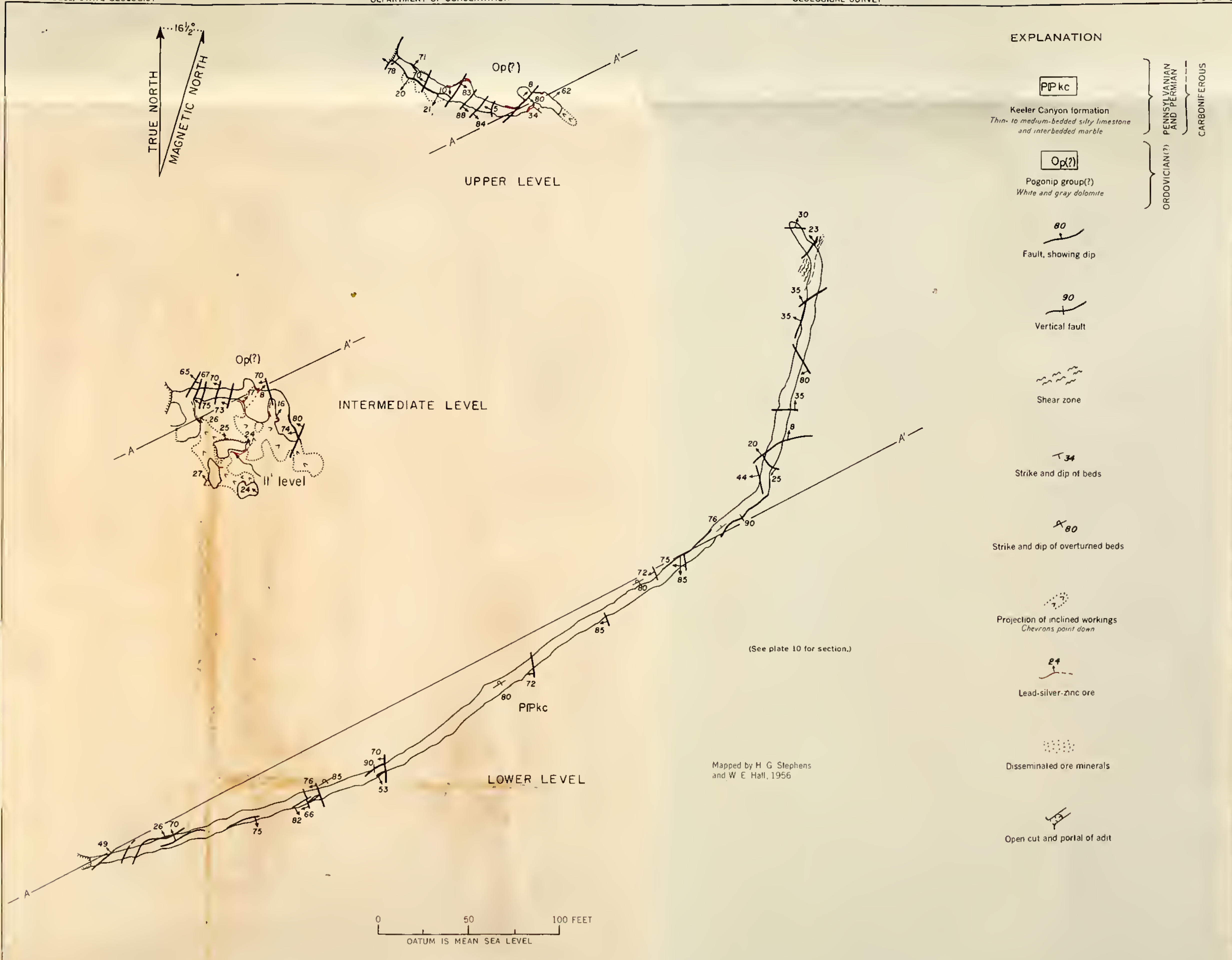
PLATE 9



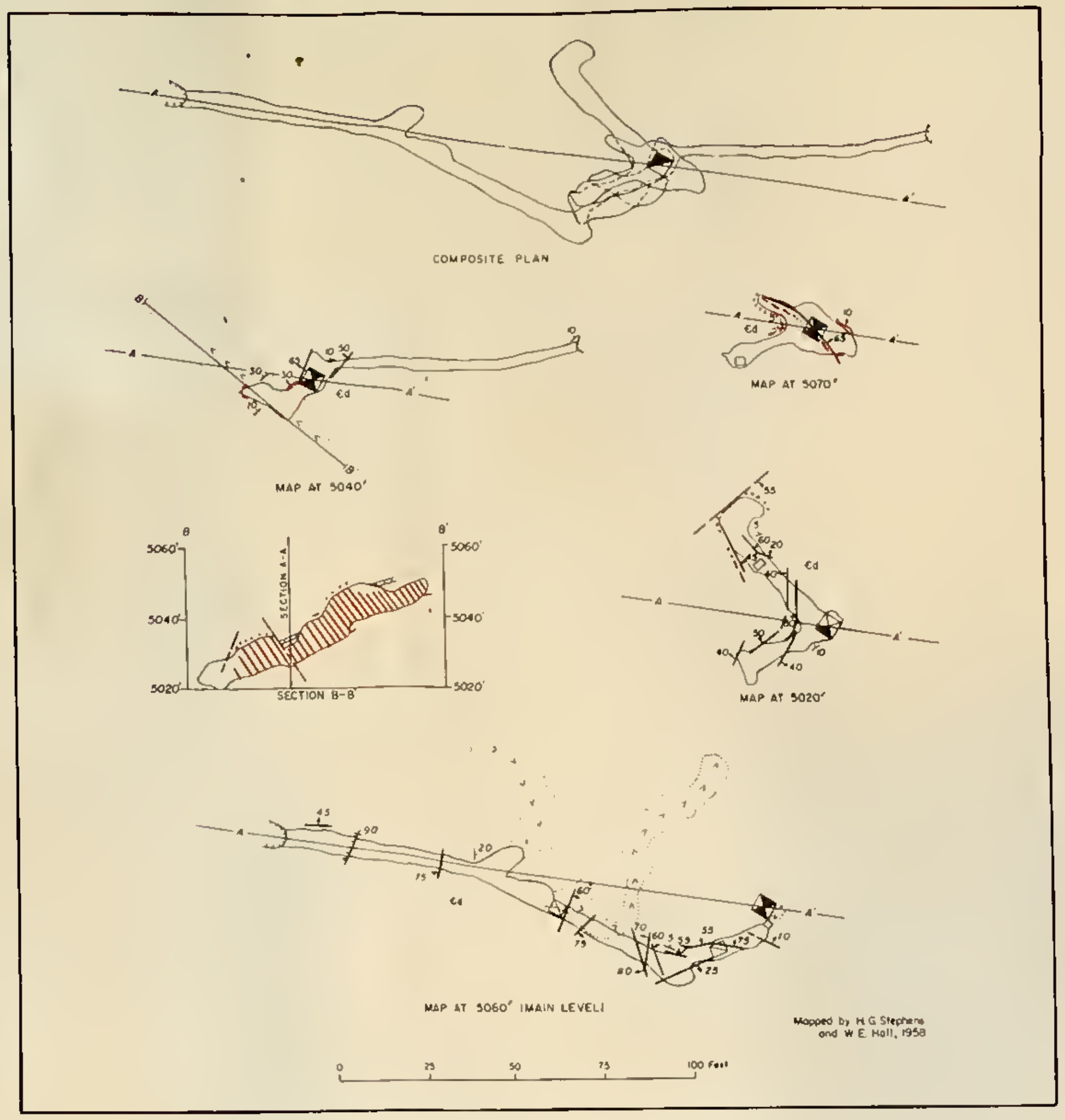
GEOLOGIC MAP AND SECTIONS OF THE SURPRISE MINE INYO COUNTY, CALIFORNIA



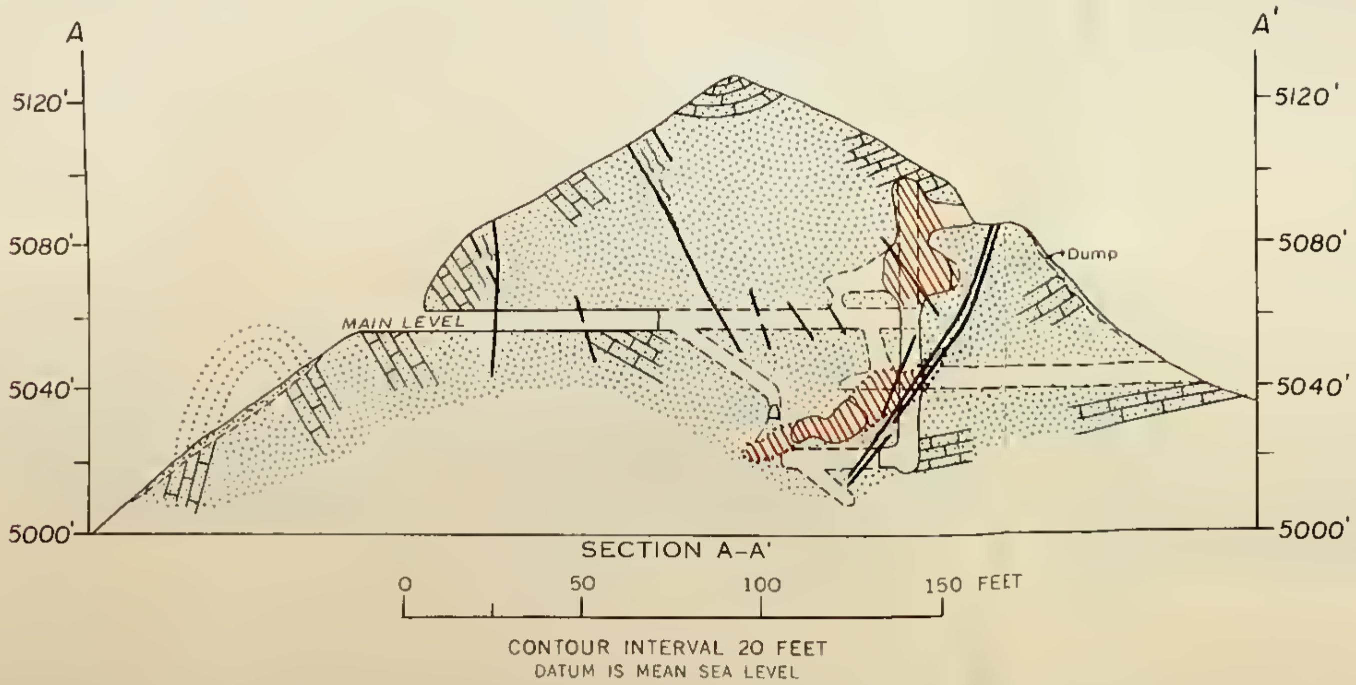
GEOLOGIC MAP AND SECTION OF THE BIG FOUR MINE AREA, INYO COUNTY, CALIFORNIA



GEOLOGIC MAP OF THE UNDERGROUND WORKINGS OF THE BIG FOUR MINE, INYO COUNTY, CALIFORNIA



MAPS OF UNDERGROUND WORKINGS



EXPLANATION

€d — Dolomite, gray medium bedded — CAMBRIAN(?)

Fault, showing dip
Dashed where approximately located

Vertical fault

Shear zone

Strike and dip of beds

Strike and dip overturned beds

Horizontal beds

Strike and dip of foliation

Anticline, showing trace of axial plane

Projection of inclined workings
Chevrons point down

Galena or secondary lead minerals

Oxidized lead and iron minerals

Outline of main level of map

Outline of workings in section
Dashed where projected

Stoped ore
Dotted where projected

Head of raise or winze

Shaft going above and below level

Shaft at surface

Bottom of shaft

Ore chute

Adit portal

Dump

Open cut

GEOLOGIC MAPS AND SECTIONS OF THE LEMOIGNE MINE AREA, INYO COUNTY, CALIFORNIA

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on

California Geology

to

December 31, 1961

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California Division of Mines and Geology
Ferry Building, San Francisco, 1963



ON THE OUTSIDE COVER . . .

Top row, right to left: Scripps Institution of Oceanography, University of California, San Diego; Allan Hancock Foundation building, University of Southern California; McGraw Hall, Cornell University.

Center row, right to left: Earth Sciences Building, University of California, Berkeley; *(inset)* Mackay School of Mines, University of Nevada; Royce Hall, University of California, Los Angeles; Geology Building, University of Arizona.

Bottom row, right to left: Rosenwald Hall, University of Chicago; *(inset top right)* Seaver Laboratory, Pomona College, Claremont, California; *(inset top left)* Geology Corner, Stanford University; *(inset bottom)* Science Building, Fresno State College, Fresno, California; Arms and Mudd Geological Laboratories, California Institute of Technology, Pasadena.

ON THE INSIDE COVER . . .

Top center, moving clockwise: Brown Hall, New Mexico Institute of Mining & Technology, Socorro; Lindley Hall, University of Kansas, Lawrence; Marion Edwards Park Hall, Science Center, Bryn Mawr College; College of Mines, University of Idaho, Moscow; Physics-Chemistry Building, Oregon State University, Corvallis; Guyot Hall, Princeton University; Technological Institute, Northwestern University, Evanston; Schermerhorn Hall, Columbia University, New York; Old Capitol, State University of Iowa, Iowa City; Geology Building, Louisiana State University, Baton Rouge; Science Hall, University of Wisconsin, Madison.

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